

# Improving Campus Safety and Sustainability by Bringing Renewable Energy Technology to the American Farm School

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**AMERICAN  
FARM SCHOOL**  
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# Abstract

Limited street lighting on the American Farm School campus in Thessaloniki, Greece presents safety hazards to pedestrians and motorists on campus roads. Through interviews, direct observation, and textual research, we identified the areas that most need increased lighting, and developed systems and funding strategies to meet these needs. To provide adequate lighting while limiting light pollution and maintaining the natural aesthetic of campus, we recommend low temperature covered LED lamps powered by roof-mounted solar panels to mitigate the long-term electricity expenses.



# Acknowledgements

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# Executive Summary

Inadequate street lighting is the primary cause of nighttime motor vehicle fatalities and serious injuries in Greece. On the American Farm School (AFS) campus in Thessaloniki, the primary roads are shared between vehicles and pedestrians and are poorly lit, proving a safety concern. Although the AFS is aware that darkness limits the usability of their campus at night, financial restrictions have prevented them from improving the outdoor lighting. A lighting system powered by renewable energy could address safety concerns, align with the AFS' ethos of environmental conservation, and serve as an educational tool to teach students about renewable energy and climate change at a low operating cost. The goal of this project was to create recommendations for how the AFS could improve nighttime safety and road visibility on campus by using renewable energy technology to power outdoor lights.

To complete this goal, we identified the following three research objectives:

1. Determine needs, priorities, and resources of the AFS regarding lighting and renewable energy technology
2. Identify suitable options for lighting solutions and renewable energy generation
3. Develop design recommendations

## Methods

For the research objectives, we analyzed AFS archives, specifically United States Agency for International Development (USAID) requests for funding, to discover the priorities of funding organizations. Through archival research, we sought to learn about past renewable energy projects and the characteristics that made them succeed or fail. To understand the current context of this project, as well as the needs and priorities of the AFS community, we conducted interviews with:

- Buildings and Ground Director
- Dean of the School for Professional Development
- Farm Director
- Faculty
- Senior Farm Staff
- Residence life Coordinator of Perrotis College
- Perrotis College students
- An adult student (continuing education)
- An American study abroad student
- A lawyer from the Hellenic Energy Regulation Institute
- Professional Development (IEK) students
- Security staff

Through direct observation, we sought to understand the safety concerns of the community by rating the nighttime lighting conditions of different roads on campus. To frame the design recommendations, we developed case studies based on visits to other farms, universities, and businesses in the USA (United States of America) that have experience with renewable energy technology. We researched lighting and renewable energy manufacturers to gain technical specifications for this project, and we read primary literature to learn about efficient lighting options and the renewable energy technologies available.

## Findings and Recommendations

We found that over 50% of the roads on the AFS campus were in a condition of moderate to extreme darkness. While students felt the campus was safe, many expressed that increased lighting would improve their feelings of safety. However, the need for additional lighting must be balanced with the AFS community's desire to preserve the natural aesthetic on campus.

Additionally, we found that students felt they had little agency over climate change mitigation, believing that their individual actions could not have much impact on the environment. Despite this, they expressed an interest in learning more about climate change and renewable energy. The faculty were also enthusiastic about the opportunity to incorporate a campus renewable energy project into their curriculum.

The following list summarizes characteristics of a renewable energy powered lighting system as identified through interviews with stakeholders on campus. The lighting system should:

1. Provide enough light for pedestrians and motor vehicles to identify and avoid each other from a distance
2. Illuminate the dark paths on the western side of campus, specifically the path from the public bus stop access to the dormitories
3. Retain the natural ambiance of campus and be aesthetically pleasing by not over lighting
4. Be financially feasible through grants or other funding sources
5. Be safe, accessible, and visible so it can be utilized as an educational tool

## Street Lighting Technology

Based on the standards of the Illuminating Engineering Society of North America (IES) and preferences of the AFS community identified through stakeholder interviews, we recommend that the potential implemented lighting adhere to the following criteria:

- Provide 10 lux of illumination at street level, enough to detect a person from 90 meters
- Use lights with 3000 K color correlated temperature to reduce glare and preserve the natural aesthetic of campus
- Use LED bulbs as they are more energy efficient, have a longer lifespan, and are less expensive than traditional bulbs
- Use consistent, dim lighting to minimize disruption to farm animals
- Cover lighting fixtures to reduce light pollution and electricity costs

## Renewable Energy Technology

We determined that a roof mounted solar panel system could be a suitable option for the AFS to power the improved lighting system due to the following findings:

- Biogas digesters have a much higher operating cost because they require a full-time employee dedicated to operating the digester, frequent maintenance, and chronic part replacement
- The AFS farm does not produce enough animal and food waste to efficiently power a digester
- With 2338 hours of sunlight per year in Thessaloniki (Weather Atlas, 2019), abundant potential exists to capitalize on solar energy
- Solar panels are the most affordable they have ever been, making now a good time to invest (Gawrych, 2019)
- Ground solar panels have higher installation and maintenance costs than roof panels and they consume valuable, cultivatable land

## Funding Options

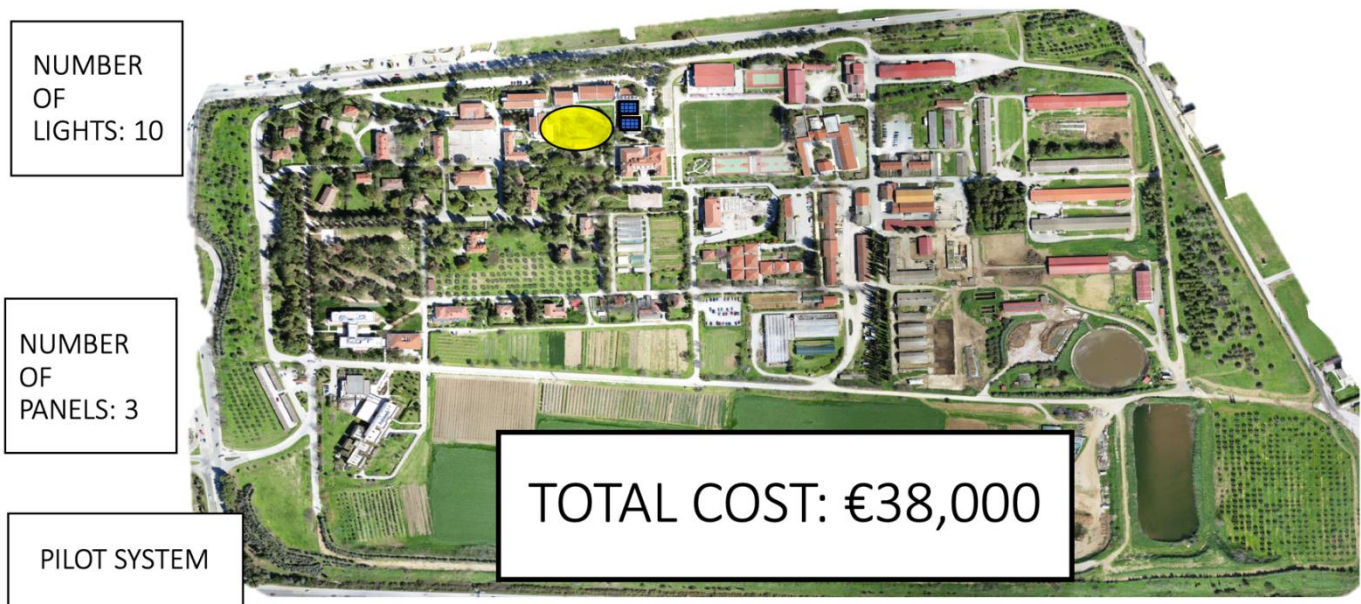
Due to the high upfront costs of materials and installation for a solar powered lighting system, we recommend that the AFS apply for external grants to fund the upfront investment of the outdoor lights and solar panels. Promising avenues for these grants are through either European Union (EU) or USA aid organizations. Due to the AFS' relationship as an approved beneficiary of USAID grants, pursuing USAID is likely to be a smoother application process than EU grants. Table 1 details two promising grant options.

*Table 1: Two promising grant opportunities for the AFS*

Funding Source	Total funds available	Award amount	Relevant Funding Priorities
<b>USAID- American Schools and Hospitals Abroad</b>	\$23 million	\$500,000- \$2,000,000	International schools that are teaching American ideals and/or helping to encourage growing societies
<b>EU LIFE Program</b>	€3.4 billion	€500,000- €1.5 million	Environment and resource efficiency, climate change mitigation and adaptation

## System Options

Even with external grants, a renewable energy powered lighting project would be a major commitment for the AFS. Therefore, we recommend that the AFS begin with a pilot system to introduce renewable energy powered lighting to campus. In 2019, students at the AFS will begin a project to redesign the landscape of the high school courtyard to make it more useable and aesthetically pleasing. Currently, only one light exists in this courtyard, and it is close to the building entrance. Illuminating the courtyard would make the area more accessible and welcoming for students. Figure 1 shows the location of the lighting and the solar panels that would power them, as well as technical details and cost estimates.



*Figure 1: Schematic of pilot system including price breakdown and technical details*

Since the pilot system has relatively low costs, it could be implemented without major external grants. Its low cost could be accompanied by significant benefits as the courtyard demonstration site has heavy foot traffic, meaning the pilot system could help gain traction and support for a larger system on campus both within and outside the AFS campus. If successful, the courtyard pilot system could be leveraged as an example of AFS experience and investment in renewable energy technology and safety to secure future funding to expand the renewable energy powered lighting system.

Based on the areas of the campus that currently have the poorest lighting and those paths that students indicated they used most regularly, we identified a primary recommended system that could benefit from improved lighting. This area includes the western half of campus and houses all students and faculty as well as the access for the public bus stop and the main entrance gate, meaning it receives considerably more traffic than the rest of campus. The system needed to power and illuminate this region is described in Figure 2.



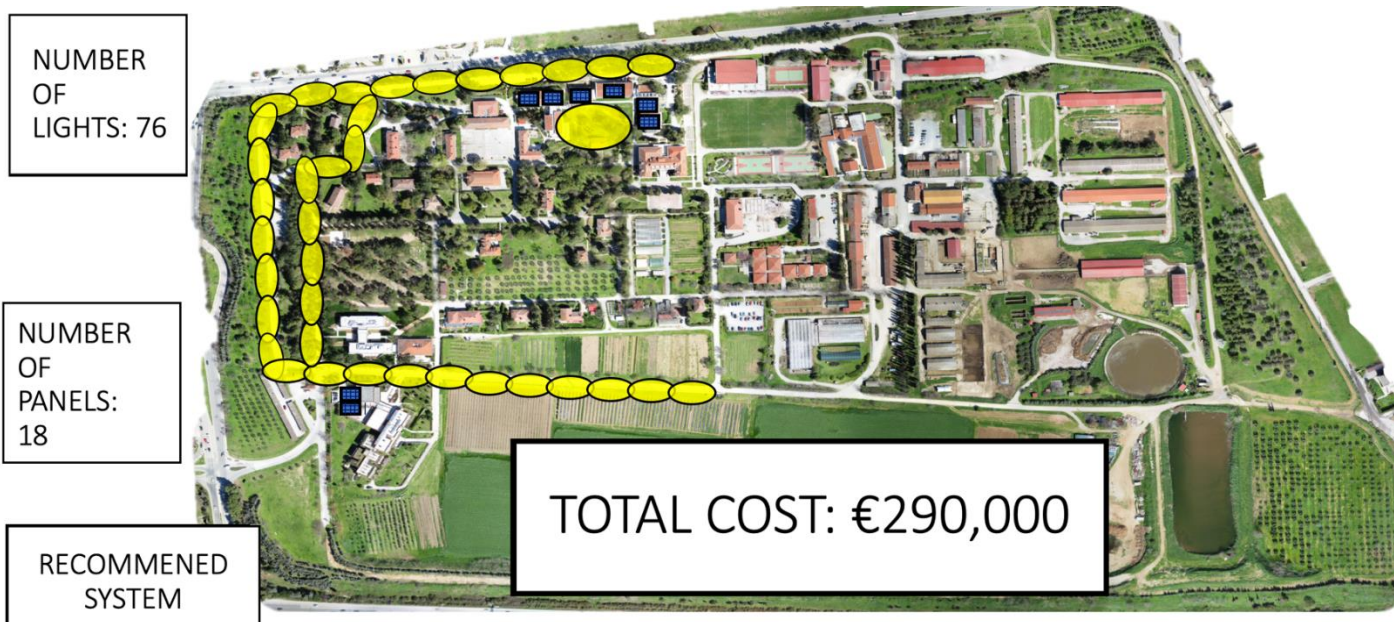


Figure 2: Schematic of recommended system including price breakdown and technical details

The system could be expanded from the recommended area until all the priority roads in need of light are addressed, using roofs around the campus to mount additional solar panels. This system is described in Figure 3. It could encompass the perimeter road which has the most automobile traffic, paths to the farm used by staff during all hours of the night and day, primary parking lots, and the path from Perrotis College to Princeton Hall. This total system would be a huge commitment for the AFS but could be completed incrementally as funding and interest become available. By initiating a renewable energy project to power outdoor lights, the AFS would not only improve safety and usability of campus, but also create an educational tool to exemplify the benefits of renewable energy technology to the students of the AFS and Perrotis College.

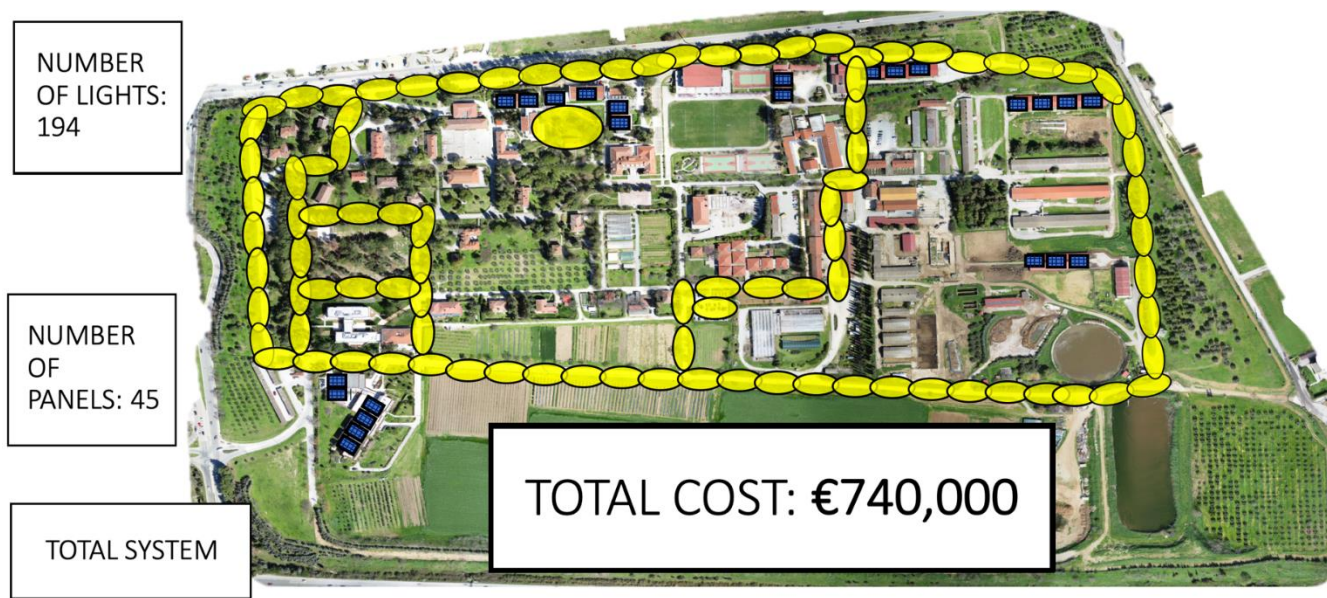


Figure 3: Schematic of total system including price breakdown and technical details



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*While this authorship section describes who took the initial leads on writing these sections, we utilized a collaborative editing process. Most of these sections are now the result of all our work and ideas and do not belong to a single individual.*

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# 1.0 INTRODUCTION

Traffic accidents are three times more frequent at night than during the day (Skandali & Lambiri, 2018). Inadequate street lighting is the primary cause of nighttime motor vehicle fatalities and serious injuries in Greece (Yannis, Kondyli, & Mitzalis, 2013). Justifiably, people feel less safe walking in the dark than in well-lit areas (Boomsma & Steg, 2014). The American Farm School<sup>1</sup> (AFS) in Thessaloniki, Greece has experienced nighttime safety concerns firsthand as the roads through the farm and the school shared between vehicles and pedestrians are poorly lit. Inadequate lighting poses a safety hazard to the students and faculty who reside on campus. More comprehensive outdoor lighting could be implemented at the AFS to improve nighttime visibility, and therefore safety.

Due to budget limitations and the high electricity costs incurred by lighting, the AFS has been unable to fund a lighting improvement project. However, renewable energy technology could reduce or eliminate additional electricity costs, creating a financially viable solution. Options for renewable energy technologies that capitalize on the AFS' resources include solar panels and anaerobic biogas digesters. Although the upfront capital costs of renewable energy technologies are significant, grants exist for schools and farms wanting to introduce renewable energy systems onto their facilities. The long-term benefits of reducing ongoing energy costs could offset the initial investment.

Using renewable energy to power an outdoor lighting system on campus would align with the school's values of sustainable farming and environmental conservation. Since their founding in 1904, the AFS has exemplified sustainable farming by using recycled wastewater on their fields and focusing on growing native crops (Marder, 2004). A renewable energy project on campus could further instill values of environmental stewardship on the student body and could help to educate them about the growing issue of climate change that threatens Greece and the world.

The goal of this project was to create recommendations for economically improving safety on the AFS campus using renewable energy technology to power outdoor lights. To achieve this goal, we spoke with stakeholders and end-users to understand the context of the project as well as the needs, priorities, and resources of the AFS regarding lighting and renewable energy. From these insights, we researched different outdoor lighting and renewable energy options and developed design recommendations. Throughout the project, we received feedback and made modifications on the project recommendations to ensure that they were upholding the needs of the stakeholders and end users. This report describes the process we used to assess lighting and renewable energy technologies, the findings from this research, and the concluding design recommendations for a renewable energy powered lighting system on the AFS campus.

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<sup>1</sup> *The AFS consists of a primary school, vocational school, and Perrotis College. They focus on teaching agriculture to farming students.*





## 2.0 BACKGROUND

The purpose of this chapter is to describe the context and considerations of this project and to highlight background research related to safety, outdoor lighting systems, and renewable energy technology. We also discuss potential funding sources as well as successful and unsuccessful past renewable energy projects at the AFS.

## 2.1 The connection between safety and lighting

Schools, businesses, and towns use outdoor lighting systems to improve safety, create feelings of safety, prevent lawsuits, improve morale, and deter crime (Fennelly & Perry, 2014). This section discusses the lack of outdoor lighting on the AFS campus, the safety concerns that accompany this lack of lighting, and the global standard lighting conditions used to maintain safety on school campuses.

### 2.1.1 Safety concerns at the American Farm School

The safety threats presented by the lack of outdoor lighting directly affect the community living within the closed campus of the AFS. Primarily experiencing these concerns are Perrotis College students, AFS high school students, and the forty families of staff and faculty who reside on campus. The AFS is also responsible for the safety of elementary school children, vocational students, and adults who are training at the AFS, as well as their educators. Though some lights illuminate primary buildings on campus, even the most populated paths are very dark at night. Many of the campus roads used by pedestrians are shared with motor vehicles. During the day, it is easier for pedestrians and motorists to avoid each other, but with the dramatic decrease in visibility at night, these roads become more dangerous for pedestrians. There is a 70% increase in nighttime road casualties on poorly lit streets compared to well-lit streets, meaning that shared paths are unsafe for pedestrians and drivers alike at night (Crabb & Crinson, 2009). Significant legal ramifications could result if an accident were to occur on school property and the organization had not addressed road safety and lighting concerns. Such was the case for *Snyder v. Allegheny school district* (1998) where the Commonwealth Court of Pennsylvania found the school district liable for \$275,237.55 when Mrs. Snyder fell and injured her wrist due to inadequate lighting (Commonwealth Court of Pennsylvania, 1998).

### 2.1.2 Using lighting to improve safety and security

The Illuminating Engineering Society of North America (IES) has published standard street lighting requirements (listed in Table 2) for safety. Many municipalities require schools to follow these standards to protect their students, staff, and visitors. These recommendations mandate providing enough light to be able to detect a person from 90 meters (Fennelly & Perry, 2014). Along with these recommendations, the *Handbook for School Safety and Security* identifies best practices for implementing a lighting system on a school campus to improve safety such as adding extra lighting near building perimeters, ensuring that lights overlap to minimize shadows, implementing an emergency lighting system in case of power outages, and covering lights to minimize glare and light pollution (Fennelly & Perry, 2014). To maintain safety, IES emphasizes that it is important to ensure that an area is well lit but not over lit. Glare can cause temporary

blindness which can be just as dangerous as no lighting at all (Fennelly & Perry, 2014). By complying with standard recommendations for safety lighting on school campuses, the AFS could improve feelings of safety and reduce the risk of vehicular accidents.

Table 2: IES school safety lighting standards

IES Lighting Standards	
<b><u>Area Description</u></b>	<b><u>Lighting Recommendation (lux)</u></b>
<b>Self-parking area</b>	10.8
<b>Attendant parking area</b>	2.15-9.69
<b>Pedestrian entrance</b>	53.8
<b>Vehicular Entrance</b>	108
<b>Building surroundings</b>	10.8
<b>Roadway</b>	5.38-21.5
<b>Perimeter of campus</b>	5.38
<b>Interior of campus</b>	4.31
<b>Security gate house</b>	269-323
<b>CCTV</b>	Detection: 5.38, Recognition: 10.8, Identification: 21.5

Table source: (Fennelly & Perry, 2014)

## 2.2 Sustainability at the American Farm School

In this section, we discuss the second motivation for this project, environmental conservation. We review the efforts of Greece and the EU to combat climate change. Then, we discuss previous environmental projects of the AFS. We describe the current financial constraints and opportunities available at the AFS. Finally, we discuss the potential for a renewable energy project to be used as an educational tool at the AFS.

### 2.2.1 Goals and investments in renewable energy in Greece and the EU

Scientists predict that by 2050, the average global temperature will increase by two degrees Celsius, even if carbon dioxide emissions are reduced to one third of their current levels (McGlade & Ekins, 2015). The European Union (EU) has established itself as a global leader in addressing climate change by setting goals to reduce carbon emission rates through investment in renewable energy. The EU has set goals for Greece to reduce greenhouse gas emissions by 18% and increase renewable energy share by 18% by 2020, compared to 1990 levels Greece took the initiative to increase these targets to 20% (European Commission, 2016). However, the Greek economic crisis, reflected in the national debt at 188.7% of the GDP in 2018 and unemployment



at 21.5% of the national labor force, makes growth and investment difficult (OECD, 2019b). While Greece is currently on track to surpass both these targets, most of Greece's energy is still petroleum sourced (OECD, 2019a). The safety concerns of the AFS, the global environmental crisis, and the difficult economic situation of Greece present a unique opportunity to use renewable energy technology to power additional lighting on the AFS campus.

### 2.2.2 Previous projects at the American Farm School: successes and failures

The AFS' dedication to environmental conservation and awareness is evidenced by their response to the rapid urbanization of Thessaloniki. In 1991, the expanding city caused the water table in the region to drop, making water a limited commodity. The pressing issue encouraged AFS administration to become leaders in the area by conserving run-off water and reducing their overall consumption of water. Since the school took the initiative to mitigate water scarcity issues, they received US \$240,000 in grants from the United States Agency for International Development (USAID), American Schools and Hospitals Abroad program (ASHA) to support their environmental protection efforts (American Farm School, 1991). Another previous renewable energy project of the AFS attempted to reduce energy consumption of the campus. USAID awarded the AFS a grant of over US \$500,000 for the construction and installation of a biogas digester, which would have been the first of its kind in Greece. Construction began in 1983; however, the project was never completed. After the grant funds were used for the up-front system costs, the school had no additional funding for the maintenance required to continue the project. The lack of sustainability of the biogas digester project caused its failure and ultimate waste of resources (American Farm School, 1983). Previous project requests that were awarded funding specifically addressed how the grant would "improve the campus, student life, and public relations", explicitly stated how the project could be continued in the future to assure sustainability, and justified the project in terms of needs, benefits, and cost-effectiveness (American Farm School, 1989). This suggests that a project that works to achieve a specific environmental and communal goal has the potential to successfully secure financial assistance.

### 2.2.3 Financial constraints and opportunities at the AFS

Although the AFS wants to improve campus safety by increasing the amount of outdoor lights on campus, the additional electricity that the lights would require would be a large cost to the school. On average, 88% of outdoor lighting system costs are solely due to electricity (Fennelly & Perry, 2014). Being as the school receives project funding from external grants, it could be difficult for the AFS to fund the continued cost of the electricity for powering a new lighting system (Vergos, 2019). However, the AFS has plentiful resources available that could power a renewable energy system, thus eliminating the need for additional electricity for the lights.

Even though the upfront cost of a renewable energy system can be a major investment, the EU and other countries have begun backing foreign investments in renewable energy technology. Banks such as the European Bank of Reconstruction and Development are investing in renewable energy projects in Greece. Last year, this bank lent €300 million for renewable energy

projects (Hirtenstein & Tugwell, 2018). Additionally, the Greek government has created cash grants and tax exemptions to encourage private renewable energy projects. For example, large Greek renewable energy companies such as the Eunice Energy Group have started to invest in renewable energy projects (Eunice Energy Group, 2018).

The AFS has historically benefited from USAID grants to fund improvement projects. In the past, the AFS has used USAID ASHA grants; however, there are many other USAID funding opportunities that encourage renewable energy projects, particularly in agriculture. USAID has partnered with countries in the EU to establish additional funding opportunities specifically for agricultural organizations looking to reduce their carbon footprint (USAID, 2018). The EU also individually provides grants to fund projects that combat climate change across Europe, such as through their LIFE program (Covenant of Mayors for Climate & Energy, 2016).

#### 2.2.4 Integrating environmental stewardship and education

The AFS has historically prioritized hands-on learning and has used technological innovations to educate its students and set an example for its community (Marder, 2004). Renewable energy technology on campus could create visibility for energy sustainability and climate change mitigation efforts. The AFS prides itself on educating the next generation of agricultural leaders and being a proactive member of the Greek community. They especially value environmental conservation and preservation. Hands-on experience with renewable energy technology could spread awareness of climate change and encourage community members to invest in renewable systems and increase the productivity and sustainability of their farms (Vergos, 2019). This aligns with the school’s mission of “educating youth and adults to... make Greece and its neighbors a better place” (American Farm School, 2019).

Shakopee high school in Minnesota, USA showcases the non-monetary benefits that could arise from a renewable energy project on a school campus. In 2013, the Shakopee high school was awarded federal and private funding for the initiation of a solar photovoltaic project that would provide the school with 100% of their electrical needs. Students of Shakopee high school gained interest in the project and took initiative to create several student environmental clubs. This renewable energy project also led to the creation of an annual showcase project called Environmental Ethics Night, where members of the community can share stories of their environmental efforts and work. Every year, primary school students in the district take field trips to the high school to learn about basic environmental topics from the older students in the environmental clubs. The Principal of the school explained how this project helps younger students get “connected with the environment while the high school students get connected with the community.” A renewable energy project at the AFS could be an opportunity to encourage the community take an active role in climate change mitigation (Changalov, 2013).

### 2.3 Initial assessment of technology options

This section discusses different lighting systems that could be implemented at the AFS and the renewable energy technologies that could power them. To capitalize on the natural resources

available at the AFS, and to provide recommendations that are feasible economically, technically, and socially, this research focused on solar photovoltaics and anaerobic biogas digestion technologies.

### 2.3.1 Solar energy

The sun produces huge amounts of energy which can be harnessed for electricity using photovoltaic (PV) technology. Rated best weather in the world in 2018, with 256 days of sunlight per year, Greece has abundant potential for solar energy generation (Maroulis, 2019). Although solar panels are only about 16-17% efficient at converting solar energy to usable electricity, they are the third most utilized renewable energy technology in Greece because of their relatively low upfront cost, minimal maintenance, and long lifespan (Atlas Energy Storage Systems, 2019; International Energy Agency, 2011). Comparisons of different types of PV technology are listed in Table 3.

Many organizations in Greece are already taking advantage of PV technology to offset their energy requirements. In 2017, Katsaprakakis and Zidioanakis published a case study of ten schools in Greece, including three in Thessaloniki, that implemented solar renewable energy systems to supply 100% of their electricity. These schools implemented PV technologies with the objective of reducing electricity consumption and providing an energy alternative to diesel fuel. The EU and Greek government completely funded these projects. The researchers found that in addition to the environmental and economic benefits of the renewable energy upgrades, the schools used these new installations as a teaching aid to promote environmental conscientiousness to the students and community. The excess electricity produced by the solar panels is directed to the electrical grid, providing an income source for the schools as well. The study concluded that the ten schools were able to improve their energy efficiency ratings and reduce their electricity costs by reducing their carbon emissions (Katsaprakakis & Zidianakis, 2017).



Table 3: Benefits and weaknesses of different photovoltaic technology types

PV Structure Description	Benefits	Weaknesses
<b>Traditional roof-mounted solar panels</b>	<ul style="list-style-type: none"> <li>- Roof space is typically unused, does not take up valuable farm land</li> <li>- panels can be directed towards the sun on flat roofs</li> </ul>	<ul style="list-style-type: none"> <li>- Flat roofs require extra infrastructure to position panels</li> <li>- May be blocked by tree coverage</li> <li>-tilted roofs that do not face south reduce efficiency</li> </ul>
<b>Parking solar canopies</b>	<ul style="list-style-type: none"> <li>- Protect cars</li> <li>- Directs rainfall</li> <li>- Can be built in the direction to capture the most sun</li> <li>- Does not take up valuable farm land</li> </ul>	<ul style="list-style-type: none"> <li>- Higher infrastructure costs compared to roof panels</li> <li>- Size is limited</li> <li>- May disrupt run-off patterns</li> </ul>
<b>Solar farm</b>	<ul style="list-style-type: none"> <li>- Most amount of space available</li> <li>- Produce more energy</li> </ul>	<ul style="list-style-type: none"> <li>- Requires more maintenance than roof panels</li> <li>- Higher infrastructure costs than roof panels</li> <li>- Uses valuable, useable land</li> </ul>
<b>High efficiency Panels</b>	<ul style="list-style-type: none"> <li>- About 3% more efficient than normal panels</li> </ul>	<ul style="list-style-type: none"> <li>- Much more expensive than traditional panels</li> </ul>
<b>Thin film PV</b>	<ul style="list-style-type: none"> <li>- Takes up less space than traditional panels</li> <li>- Aesthetically pleasing</li> <li>-Easier to install than traditional panels</li> </ul>	<ul style="list-style-type: none"> <li>- Less efficient than traditional panels</li> <li>- Higher cost than traditional panels</li> </ul>
<b>Concentrating PV</b>	<ul style="list-style-type: none"> <li>- Much more efficient than traditional panels</li> </ul>	<ul style="list-style-type: none"> <li>- Take up much more space than traditional panels</li> <li>- Much more expensive than traditional panels</li> </ul>

Table sources: (Gawrych, 2019), (Atlas Solar Innovations, 2019)

### 2.3.2 Biogas digestion

Another suitable form of renewable energy technology for the AFS is biogas digestion, as the farm has 220 milking cows producing waste that could be used as feed for a biogas digester (Vergos, 2019). Figure 4, shows a basic overview of the process. Farmers collect organic waste such as animal manure and food waste for the anaerobic digestion tank. The naturally occurring microorganisms in cow manure digest organic waste into useable products. The main product, biogas, is converted to methane and burned to produce electricity (American Biogas Council, 2019). The digestate byproduct is separated into its liquid and solid components which can be used for concentrated, organic fertilizer and animal bedding, respectively. Additionally, the process of anaerobic biogas digestion completely eradicates the unpleasant smell of manure. This

process allows an anaerobic digester to serve as a lynchpin in a circular economy model of energy generation. Instead of linear energy generators that intake raw materials and generate waste, a digester uses a waste product to generate useful resources while replenishing the soil and generating energy. The digester feeds back into the cycle that originally generated the waste to create a positive feedback loop, allowing for efficient and sustainable operation (MacArther, 2017).

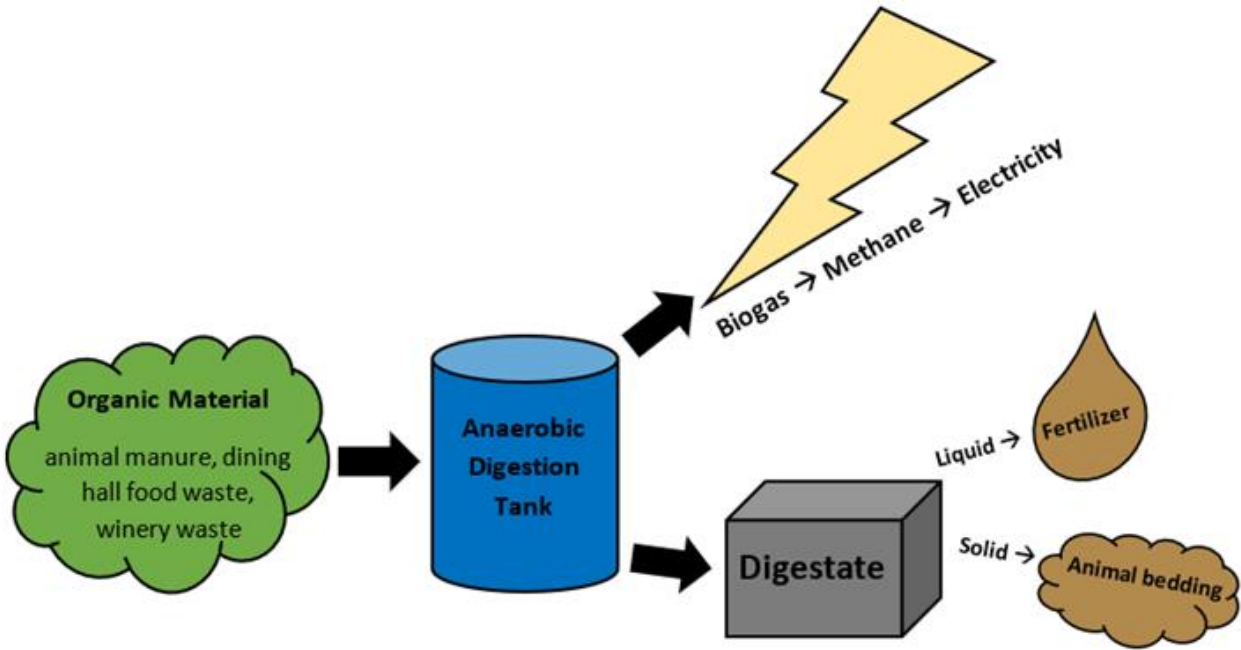


Figure 4: Schematic of biogas digestion process

### 2.3.3 Lighting technology

Lighting systems are considered a central component of safety for schools (Fennelly & Perry, 2014). Currently, most systems use either fluorescent, high-pressure sodium (HPS), or LED lights. LED lights consume less energy per lumen emitted, last for three times as long on average, and require infrequent maintenance compared to traditional HPS lights, making them the less expensive option (Getu & Attia, 2016a). LED bulbs contain less noxious chemicals than fluorescent lights, making them safer and more environmentally friendly as well (Getu & Attia, 2016b). In addition, LEDs can be produced in a range of colors, allowing lighting to meet the narrow amber band of color (3000 K correlated color temperature) suggested by published safety standards to reduce glare (Traverso et al., 2017). Lights with lower correlated color temperatures are also more visible through fog, making them preferable for safety lighting (Traverso et al., 2017). Fog is frequent and severe in northern Greece as exemplified by numerous annual airport closures at Thessaloniki Airport Makedonia (Stolaki, Kazadzis, Foris, & Karacostas, 2009). A study conducted over thirty-five years found that Thessaloniki Airport averages 18 fog events annually (Stolaki et al., 2009). 75% of these fog events reduced visibility to 400 meters, creating severe visibility problems (Stolaki et al., 2009). LED lights with low correlated color temperatures that can penetrate fog could improve safety for both vehicles and pedestrians on the AFS campus.



## 3.0 METHODOLOGY

To create recommendations for the AFS to implement a lighting system powered by renewable energy technology to improve campus safety, reduce energy costs, and limit environmental impact, we identified the following three research objectives:

1. Determine needs, priorities, and resources of the AFS regarding lighting and renewable energy technology
2. Identify suitable options for lighting solutions and renewable energy generation
3. Develop design recommendations

We organized the project objectives around the IDEO<sup>2</sup> human centered design process of empathize, define, ideate, prototype, and test, with community feedback driving every objective to design a proposal that was suitable for the AFS. Figure 5 describes the stages of the design process we used. As described by IDEO, human centered design will “help [you] connect better with the people you serve...and transform data into actionable ideas” (IDEO, 2015). The goal of human centered design is to make a project more sustainable by having it driven by the user. This way, it upholds the values of the community it serves and reflects their needs. This chapter explains the objectives of this project and the data collection and analysis procedures used to achieve these objectives.

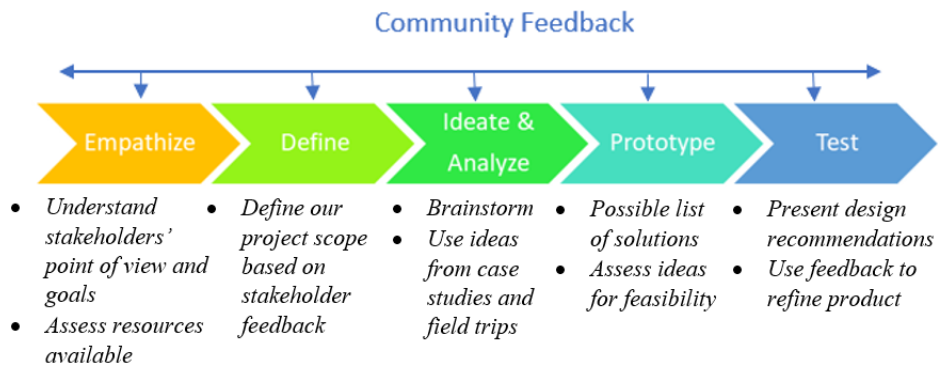


Figure 5: Design process overview (IDEO, 2015)

### 3.1 Objective 1: Determine needs, priorities, and resources of the AFS regarding lighting and renewable energy technology

In this stage, we sought to understand the problems of the stakeholders to create solutions that were desirable and feasible for them. The research questions for this objective were:

1. How safe is the AFS campus, and how could feelings of safety be improved?
2. How much lighting currently exists on campus?
3. Which areas most need additional lighting?
4. What are the aesthetic preferences of the campus community regarding lighting and renewable energy technology?

<sup>2</sup> IDEO is a global consulting and innovative design company that expanded the ideas of human centered design used in this project from Stanford Design School (IDEO, 2015).

We researched AFS archives with the intention to understand previous safety and renewable energy initiatives of the school. To align this project with the current concerns and interests of the campus, we conducted interviews with students, faculty, the Buildings and Grounds Department, Dr. Evangelos Vergos<sup>3</sup>, and campus security. We questioned stakeholders about campus appeal to determine the factors that are aesthetically important to them. Through interviews, we identified resources and space available for a renewable energy project and directed this research to focus on the renewable energy technologies that capitalize on the assets of the AFS. To understand the context of this project as experienced by the end user, we walked the campus roads and paths and recorded observations.

With the assistance of AFS librarians, we examined archives specific to AFS policies, their mission, and historical data. We used this data to identify why previous renewable energy projects failed and how we could avoid similar pitfalls. In historical data, we investigated the original goals of the AFS to align this project with the school's mission and context.

To understand the current culture, we spoke to students and residents of the AFS campus. We interviewed 14 Perrotis College students in groups ranging from 1 to 5 students, a group of 4 IEK (Professional Education) students, and one adult continuing their farming education at the AFS. From these interviews we hoped to gain contextual information about the safety of campus, specifically students' needs and preferences regarding additional lighting on campus. These interviews were kept anonymous to mitigate social biases and protect the privacy of the students. A compiled record of student interview responses is listed in Appendix B. In addition to students, forty families of faculty live on the AFS campus and experience the lack of lighting (Vergos, 2019). We interviewed 8 faculty members to discover how safe they and their families feel on campus, both walking and driving, and how they believe safety could be improved. To determine where additional lighting could be beneficial, we had students and faculty interviewees identify their most commonly traveled routes on a map of campus. We compiled these results to identify the most frequented routes of campus. With permission, faculty interviews were not anonymous. We risked losing information due to a language and cultural barrier, but we mitigated this risk by speaking only to students and faculty who were comfortable speaking in English.

Through student interviews, we also gauged interest level and perspectives of renewable energy and climate change. Through faculty interviews, we determined interest in using renewable energy to teach about climate change. We wanted to learn how, if at all, they thought a renewable energy project on campus could affect the students and the community as a whole. To develop recommendations for how this project could be used as an educational tool, we interviewed faculty to understand the current AFS climate change curriculum.

To understand technical details about the safety risks on campus and the resources available for a renewable energy project, we interviewed the AFS Farm Director, the Director of Buildings and

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<sup>3</sup> Dr. Evangelos Vergos, Dean of the School for Professional Education and Farm Director, worked with us throughout this project. He guided our research and aided with navigating connections at the AFS and Greece.



Grounds, security staff, and senior farm staff of the dairy, poultry, and horticulture departments. We sought to identify the areas of campus that pose the highest safety risk, and those that could benefit most from increased lighting by recording the most commonly traveled paths and the darkest paths as identified through interviews. We interviewed security guards to discuss current safety policies and how safety could be improved. We used information about past safety incidents to direct the recommendations. We interviewed the AFS Director of Buildings and Grounds to determine campus dimensions, available space, and farm production capacity to specify the technical requirements for the system. To better understand the permitting process of initiating a renewable energy project and to focus the project scope within legal boundaries, we interviewed a legal representative of the Hellenic Energy Regulation Institute. We corresponded with renewable energy manufacturers to determine the technology options that were economically reasonable for the AFS to pursue. With permission, the interviews were not kept anonymous to provide reputability to the recommendations.

To understand the concerns and motivations of the stakeholders and end users, we walked the campus with the map shown in Figure 6, both during the day and at night, to observe the lighting conditions of roads and paths identified by Dr. Vergos, students, and residential faculty. We divided sections of the roads and paths, subjectively, based on their lighting conditions and ranked each zone on a scale of 1-4 as follows:

- 1: Adequately lit, minimal shadows obstructing views
- 2: Minimally lit, exhibits significant glare or shadows
- 3: Dark, some light distantly in sight, severe shadows
- 4: Extremely dark, no lights in sight, need a personal light to navigate

Any zones marked 3 and higher indicate inadequate lighting for safety. Using Google Maps, we then measured the distances of the priority areas to determine the dimensions of lighting required. We sought to determine the amount of light necessary to improve the safety of the campus and to better understand the physical context of this project.



*Figure 6: Map of the American Farm School*

## 3.2 Objective 2: Identify suitable options for lighting solutions and renewable energy generation

In this objective, we researched solutions for potential lighting systems and renewable energy technologies that could power them. We sought to identify information about grants and funding sources that could help realize these solutions. For this objective, the main research questions were:

1. Which lighting systems would be suitable for the AFS priority roads?
  - a. How many lights and lighting fixtures are required?
  - b. Is there a long-term energy saving potential from the improved lighting technology?
2. Which renewable energy systems would be most suitable to power these outdoor lighting systems?
  - a. How have other organizations successfully implemented renewable energy technologies? How do the conditions of the sites compare to the AFS?
  - b. How much energy is required to power the lighting system?
3. What is the budget/available funding for a lighting-renewable energy project? Are there external funding opportunities for the AFS?

Information about the needs, priorities, and resources gained in Section 3.1 provided us with preliminary criteria to generate potential solutions. From case studies and research online, we sought to identify areas of further research and questions for the ideation process of this project. We specifically focused on exploring economically and environmentally conservative solutions for the AFS. We researched technical specifications of potential lighting systems by analyzing case studies of institutions that successfully implemented additional outdoor lighting and/or renewable energy systems, and by researching lighting manufacturers online. We compared the successes and pitfalls of case studies and compared these examples to the conditions at the AFS. We also conducted an interview with the Buildings and Grounds Director to learn about specific lighting and energy details and information specific to the AFS. Interview questions are listed in Appendix B. With permission, interviews were not kept anonymous.

To meet the economic requirements of the potential systems, we investigated potential grants and funding opportunities that could offset the initial and long-term costs of establishing a renewable energy project. Through grant research, we sought to find funding sources that could be obtainable for the specific conditions of this project. Through archival research, we examined past grant applications and project proposals to identify key aspects of successful projects.

### 3.2.1 Suitable options for lighting solutions

Focusing on Greek and European lighting manufacturers, we compared different lighting systems based on the following criteria:

1. Capital costs- installation and infrastructure required
2. Recurring costs- maintenance requirements and electricity cost
3. Estimated life span of bulbs
4. Lighting quality and rating- lumens emitted and correlated color temperature
5. Energy efficiency- energy required per lumen emitted
6. Aesthetics- appearance of the lights (eg: glares, shadows) and contribution to light pollution

We sought to correspond with outdoor lighting companies near Thessaloniki and analyze case studies to estimate lighting costs for the priority areas identified in Objective 1. To determine the lighting quality and ratings, we researched available lights to assess if they met school safety lighting standards identified in Section 2.1.2 of this paper. Analysis of these findings were used to narrow in on specific lighting systems to further pursue in Section 3.3. Based on interviews in Section 3.1, we sought to develop an understanding of aesthetic preferences of the campus. To take this into consideration, we aimed to evaluate how disruptive the different lights could be based on their physical appearance and the amount of additional illumination they could bring to the campus.

### 3.2.2 Suitable options for renewable energy generation

We sought to use interviews and case studies to develop recommendations for how the AFS could efficiently and economically produce electricity for the improved lighting system at the AFS. We compared different renewable energy technologies based on the following criteria:

1. Capital costs- installation and infrastructure required
2. Recurring costs- maintenance requirements and electricity cost
3. Resources required- space/location required and fuel input requirements
4. Efficiency- amount of electricity produced
5. Electricity storage possibilities (for example: batteries)
6. Aesthetics- appearance of the renewable energy system
7. Tangential benefits- benefits in addition to electricity production

We visited farms, schools, and businesses that utilize renewable energy to gain a more practical understanding of successful renewable energy projects and how they are used to improve the organization. On these visits, we collected quantitative data on the efficiencies and requirements of different systems. We conducted non-anonymous interviews and took photographs of their systems and facilities to provide further context and visual aids for this report. We researched energy storage options for the technologies so that energy could be provided to the lighting systems throughout the night. We used photographs and interview suggestions from case studies

to compare the aesthetic appeal of different renewable energy. We also used information gained through online research and interviews to identify any tangential benefits beyond the direct purpose of the renewable energy technology. We compared the conditions of the sites visited to the conditions of the AFS to direct further research and recommendations. We aimed to identify strategies to implement a range of renewable energy solutions that could be sustainable and economical for the AFS.

### 3.2.3 Internal and external funding opportunities

Considering that the AFS relies on external funding to initiate new projects on campus, we researched options that the AFS could pursue to fund the installation of an improved lighting system powered by renewable energy. Through archival research, we examined past AFS project funding requests. We used this information to identify external funding sources to determine which of the lighting systems and renewable energy technologies could be viable. In addition to historical data from the AFS, we researched external and foreign grants and funding sources that the AFS could pursue in parallel to the design recommendations. We analyzed grant reports in an effort to determine priorities of funding organizations and identify key aspects that made past applications and projects successful.

## 3.3 Objective 3: Develop design recommendations

To achieve this objective, we sought to recommend lighting and renewable energy design solutions that were technically and economically reasonable. The research questions were:

1. How do the potential lighting systems compare to criteria identified in Section 3.2?
2. What is the return on investment of the recommended systems?
3. How can the lights be used in combination with renewable energy technology?
4. What are the legal restrictions and permitting requirements to initiate a renewable energy project?
5. How can the AFS use a renewable energy system as an education tool?

Criteria for comparing the benefits and drawbacks of the potential comprehensive systems are listed here:

1. Total cost of system- Installation, maintenance requirements, and infrastructure requirements
2. Total energy consumed by lights in entire system
3. Total energy producing potential of renewable energy system
4. Long term return on investment

We combined preferences and needs from Section 3.1 with potential lighting and renewable energy technologies from Section 3.2 to develop design recommendations for a total system. We sought to develop multiple renewable energy powered system recommendations so that the AFS

could choose which area, or combination of areas, to invest in depending on funding availability. During this process, we aimed to assess the tangential benefits from the proposed lighting and renewable energy system as well as any potential unintended drawbacks of the system, such as aesthetic consequences, physical location issues, or social implications.

To create renewable energy recommendations, we researched technology options that were locally available in Thessaloniki. We contacted suppliers to obtain price and energy producing potential estimates. From this information, we aimed to calculate the specific lighting and energy requirements for the identified areas of priority and long-term return on investment potential of the renewable energy system based on energy production rate and total system costs.

In addition to the technical and financial feasibility analysis, we researched Greek laws pertaining to electricity and renewable technology. We spoke to a lawyer from the Hellenic Energy Regulation Institute to understand the permitting process and legal restrictions that apply to the AFS. Finally, we sought to create suggestions for how the AFS could use renewable energy technology as an educational tool. From student and faculty interviews we determined the community's level of knowledge and interest in climate change and renewable energy. We used this information to attempt to identify potential benefits the system could have on the student body, faculty, and residential community.





# 4.0 FINDINGS

In this chapter, we begin by summarizing the safety needs and priorities as well as the renewable energy resources of the AFS based on conversations with stakeholders and end users. We then consider current options for lighting solutions and renewable energy generation based on case studies and manufacturer information. We identify grants and funding sources from reviewal of AFS archives and textual research. Finally, we discuss electrical connectivity options for the AFS and the current legal process for renewable energy systems.

## 4.1 AFS needs, priorities, and opportunities regarding safety and renewable energy

In this section, we examine information gained from interviews with stakeholders and end users to determine the safety and lighting needs on campus as well as the financial limitations of the school. We then identify opportunities for external funding to realize the system. Lastly, we explore tangential benefits of a renewable energy project on campus and discuss its potential educational value to the students of the AFS and Perrotis College.

### 4.1.1 Safety needs and lighting preferences of the AFS community

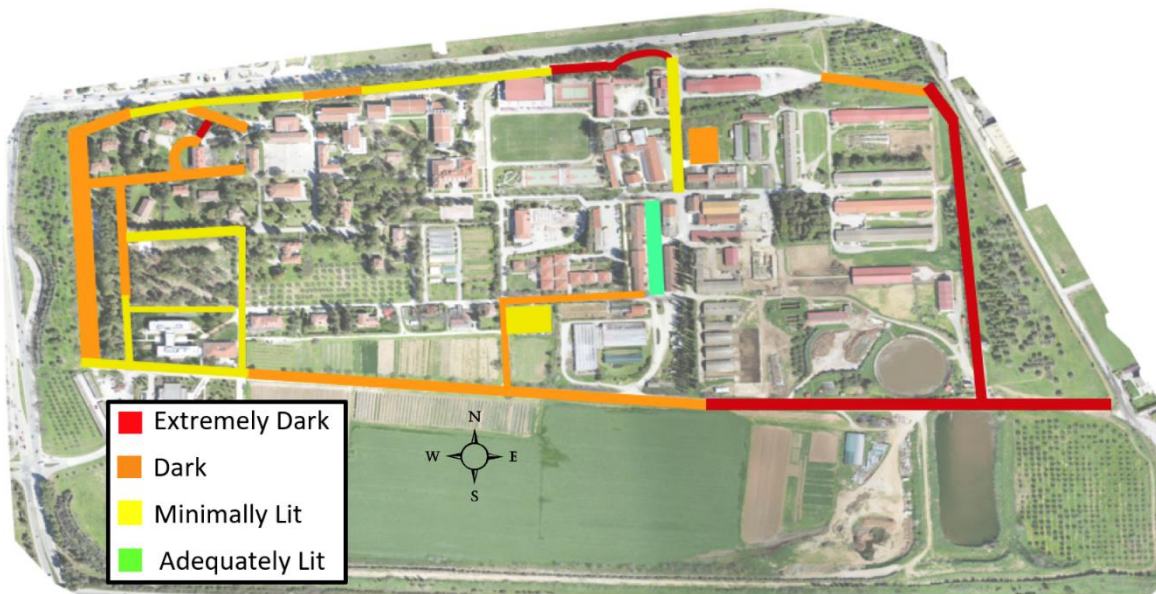


Figure 7: Map of lighting levels of AFS campus roads

**Poor lighting on the perimeter road makes it difficult for drivers and pedestrians to navigate campus.** Cars are mainly limited to the perimeter road around campus; however, through direct observation, we identified this road as having the worst outdoor lighting on campus, as depicted in Figure 7. Through direct observation, we found that almost the entirety of the perimeter road was dark with over 25% being extremely dark with no lights in proximity at night. No part of the perimeter road has enough lighting to meet the published school lighting safety standard of detecting a person from 90 meters. Inadequate lighting on the perimeter road

makes it difficult for cars to identify pedestrians. This is especially concerning as the high school dormitories, Perrotis College dormitories, and access to the public bus stop are all located on this road. Therefore, every student we interviewed reported traveling along the perimeter road regularly. In addition to students, senior farm staff identified the perimeter road, especially near the farm, as needing increased lighting. In particular, they indicated the two wheel baths on the perimeter road filled with anti-bacterial water, which are difficult to notice without lights. These could cause injury to pedestrians or damage to vehicles who are unfamiliar with campus roads. Due to the wheel baths and other farm equipment, the east side of campus does not have enough light to safely allow vehicular traffic through it at night. Faculty and staff who routinely drive campus at night and who are aware of the poor visibility described their efforts to drive slowly on all areas of campus. However, Head of the Horticulture Department, Yiannis Gatzolis, described a fifteen-minute period twice a day when parents dropping off and picking up their children drive too fast “as if they are still in the city”, creating a safety hazard for pedestrians on campus. The Resident Life Coordinator of Perrotis College, Pantelis Hantzaras, described the difficulties of identifying pedestrians walking from side paths onto the perimeter road at night and described multiple situations where collisions almost occurred due to the poor lighting.

**The east side of campus does not have nearly enough light at night to safely allow vehicular traffic through it.** The Head of the Dairy Department, Efstratios E. Souglis, expressed concern for himself and his staff as they tend to animals at all hours of the day and night on the east side of campus and there is currently no lighting on their regular routes. This makes it difficult even for staff who have worked at the school for years to orient themselves, and it makes driving around the farm before sunrise difficult. Furthermore, the east side of campus has been receiving increased traffic due to the urbanization of the surrounding neighborhood. Dr. Vergos reported that the eastern gate may eventually become the main campus entrance because of the increased traffic.



Figure 8: Map of AFS campus roads by frequency travelled (darker blue indicates more frequently travelled)



**The western half of campus receives the most foot traffic and is most in need of additional lighting.** While it is not as dark as the eastern section, according to interviews and direct observation, the western half of campus receives significantly more pedestrian traffic, making it a safety priority. In interviews, students highlighted their regular routes on a map of campus, as depicted in Figure 8. The darker the color, the more frequently students identified the path as commonly traveled. These maps show that the western half of campus is significantly more traveled than the eastern half. On the northwest of campus are both the entrance gate to the public bus stop and the high school dormitories, making this an important area for many residents of campus. Students also overwhelmingly reported that the path from Princeton Hall to the Perrotis College academic buildings and dormitories is their primary route. The importance of the western half of campus to students makes this area a safety priority.

**The paths highlighted in red in Figure 9 show the areas that could benefit most from increased lighting based on a combination of information from Figure 8 and Figure 9.** This recommended area includes the western half of the shared use perimeter road from the high school dormitories to the Educational Vineyard, including the wheel bath that is near the Perrotis College dormitories. Additionally, the pedestrian path from the public bus stop access down to the Perrotis College dormitories was indicated as needing increased lighting as it has some of the heaviest tree cover while also experiencing the most pedestrian traffic, especially at night.



*Figure 9: AFS priority roads that most need improved outdoor lighting*

**Feelings of safety of students and residential faculty on campus could be improved by increasing the outdoor lighting.** Despite road visibility concerns, from interviews with AFS students, faculty, and staff, we found that the AFS community overwhelmingly agrees that the campus is safe because entrances are gated, and the campus is patrolled by guards every hour of the night. However, 83% of female student interviewees believed that

increased lighting could improve their feelings of safety while walking the campus at night. Despite efforts to mitigate the cultural and language barrier between this team and the interviewees, it should be noted that the students did not relate the word “safety” with car accidents. We had to ask follow-up questions to learn about their experiences and feelings about cars on campus. Many students indicated that cars of visitors drive very quickly, and very few vehicles stopped at cross walks. That said, none of the students interviewed had been involved in a car accident on campus, and very few had had a negative experience with cars on campus.

#### 4.1.2 Funding opportunities

**Greece has established programs to help fund renewable energy projects.** Laws 4410 (2016) and 3851 (2010) in Greece established a Feed-in-Premium program to encourage renewable energy projects (Assimakis & Kitsilis, 2016). Cash grants, leasing subsidies, and tax exemptions have been established to cover up to 50% of renewable energy project costs in Greece (Assimakis & Kitsilis, 2016). These can help to ease the upfront costs of a renewable energy project within the country but could not completely cover the capital expenses.

**Grants from the USA and the EU, such as those detailed in Table 4 could fund a renewable energy powered lighting project on campus.** The AFS is already an approved beneficiary of USAID programs and has received funding from the organization in the past, which makes applying for funding for a renewable energy project a more reliable option. In 1982, the AFS received US \$270,000 for a renewable energy project (American Farm School, 1982). This suggests that grants of similar amounts could be pursued by the AFS for future renewable energy projects. Although renewable energy systems have high upfront costs, with government funding and external investors offsetting costs, the long-term savings can make renewable energy technologies an economical choice as well as an environmental one.



Table 4: Potential external funding sources

Funding Source	Total funds available	Award amount	Relevant Funding Priorities
<b>USAID- American Schools and Hospitals Abroad</b>	\$23 million	\$500,000- \$2,000,000	International schools that are teaching American ideals, helping to encourage growing societies
<b>USAID (Europe and Eurasia): grant applications</b>	\$308.8 Million	\$2 Million (Max)	Counter Russian Influence and strengthen the defense and economy of eastern and southern Europe
<b>European Union Rural Development Programme (EAFRD)</b>	€100 billion (€75 million for renewable energy projects in Greece)	At least €60,000	European agricultural projects that have social, economic, or environmental objectives
<b>EU LIFE Program</b>	€3.4 billion	€500,000- €1.5 million	Environment and resource efficiency, climate change mitigation and adaptation

Table Sources: (Covenant of Mayors for Climate & Energy, 2016), (USAID, 2018)

### 4.1.3 Educational opportunities presented by renewable energy technology

**Students do not believe that their individual actions can help mitigate climate change and they are not aware of the benefits of renewable energy technology.** Although Perrotis College encourages students to become more environmentally responsible through events such as the EcoOlympics, interviews with faculty and students suggested that while Perrotis College and IEK (Institute for Professional Development) students understand the impact of climate change, they do not feel they have much agency to combat the effects of it. One of the Perrotis College students said, “There is nothing I can do to actively combat global warming.” These feelings of powerlessness in the face of climate change prevent individual students from taking the initiative to be environmentally conscientious.

**A renewable energy system could be used as an educational tool at the AFS for teaching about climate change and sustainability topics.** A renewable energy project on campus with immediately visible benefits to the community, could encourage students to become more mindful of their actions and habits pertaining to environmental conservation and become empowered to take the initiative to help to mitigate climate change. Konstantinos Zoukidis, lecturer of first and second-year students at Perrotis College and teacher of IEK technical courses, stated that students “need successful examples of renewable energy technology that [they] can learn from.” He and other faculty expressed enthusiasm to incorporate examples

of renewable energy technology on campus into their lessons. A renewable energy project on campus could improve students’ awareness about the benefits of renewable energy and climate change. As described by the Deputy Director of the Junior College, Anna Papakonstantinou, “If [renewable energy] had obvious results, many students would want to incorporate it into their farms.” The students at the AFS come from communities across Greece, and after graduation they take back lessons they learn at the school. By introducing a renewable energy project to students, the AFS could encourage the next generation of farmers across Greece to embrace renewable energy.

## 4.2 Suitable options for lighting solutions and renewable energy generation

In this section, we describe options for outdoor lighting and the potential renewable energy technologies that could power them on the AFS campus. We present a range of technology options that we combine into one comprehensive system recommendation in Section 4.3.

### 4.2.1 Lighting system options

**LED bulbs with a warm color correlated temperature of approximately 3000 K CCT are a suitable choice for the AFS.** Table 5 shows a comparison of an LED bulb and an equivalent HPS bulb (Crist, 2018), (Philips, 2019). The LED bulb has a lower power draw, higher lumen per watt luminosity, longer lifespan, and better color correlated temperature (CCT). Lower temperature lights use less energy, reducing environmental as well as economic impact (Traverso et al., 2017). Keeping lights at a low CCT reduces the harmful effects of light pollution on plants, animals, humans, and the natural environment (Falchi, Cinzano, Elvidge, Keith, & Haim, 2011). Additionally, lower temperature lights are more aesthetically pleasing as they are more subtle than the bright white lights of the typical LED bulbs that are above 4000 K CCT. In interviews, students expressed concerns about over-lighting detracting from the natural aesthetic of the farm campus. One interviewee stated, “I like to walk on campus when it is dark because it makes me feel connected to nature.” The AFS feels like a rural oasis in a bustling, urban city. The community adamantly wants to protect this peaceful environment and by ensuring that lights do not disturb the campus.

Table 5: Comparison of an LED versus HPS bulb

	EcoSmart LED bulb (100W)	Philips E40 HPS bulb (100W)
<b>Power draw (W)</b>	14.5	100
<b>Lumens emitted (lm)</b>	1574	9,400
<b>Luminous (lm/W)</b>	108.55	94
<b>Approx. lifetime (hrs)</b>	50,000	24,000
<b>CCT (K)</b>	3000	1900
<b>Price (€/bulb)</b>	1.55	2.67

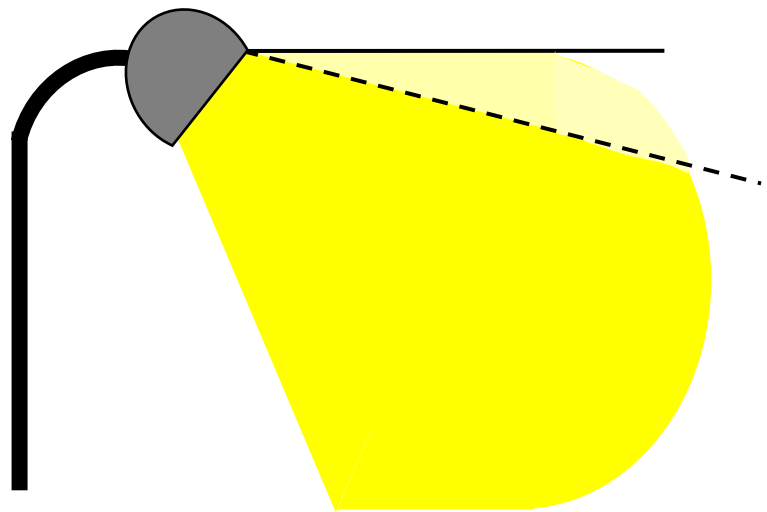
Table sources: (Crist, 2018), (Philips, 2019)

**Shielded lighting fixtures improve energy efficiency and limit light pollution, making them a suitable choice for the AFS.** Full cut-off shielded lighting fixtures that direct light downwards and keep 90% of glare within 80 degrees of the horizontal mitigate light pollution, reduce wasted energy from unnecessary light, and protect pedestrians from glare (City of Toronto, 2017), (International Dark Sky Association, 2019). Lights without covers waste electricity on light that pollutes into the sky, away from the road. The current light fixtures around campus, as seen in Figure 10, are energy inefficient and contribute to light pollution due to their undirect, diffused light. Comparatively, full cutoff lighting fixtures such as the fixture from Kim Lighting seen in Figure 11, which is certified by the International Dark Sky Association, are inexpensive alternative lighting solutions (International Dark Sky Association, 2019).



*Figure 10: Example of an ineffective outdoor light that is negatively contributing to light pollution on the AFS campus*

**Four-meter-tall lighting fixtures should be spaced 18 meters apart to create consistent lighting without gaps, shadows, or glare (Radetsky, 2011).** Lights on school campuses or in regions of similar activity are typically at four meters tall to provide adequate lighting. From this height, the LED light loss factor, and the school lighting standard of 10 lux at street level, we calculated that the lights should be spaced 18 meters apart. To see the calculations used to determine light pole spacing, see Appendix C. For our calculations, we assumed that the lights would have some overlap and be directed to the center of the path to minimize shadows and reduce wasted light (Fennelly & Perry, 2014), (Flagstaff Zoning Board, 2017). Figure 12 shows a diagram of this described lighting set up.



*Figure 11: Fully shielded light illustration showing glare reduced to 80 degrees of the horizontal*

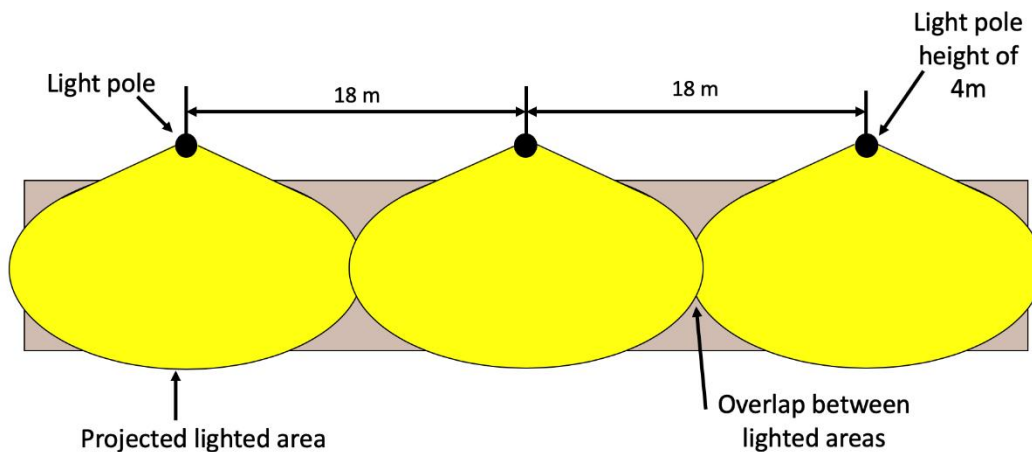


Figure 12: Diagram of a potential outdoor lighting setup

**A centralized control system is necessary to maintain consistent lighting at the AFS.**

Different lighting zones can be connected to a server where the entire system network can be controlled on a remote work station from a laptop or computer (Wilbur & Poplawski, 2015). The sectional and whole system control make a centralized system an energy efficient and safe solution for an educational institution (OSRAM, 2019). Additional benefits of a centralized control system include reliable, long-range connection, easy accessibility and user interface, and quick override features (Philips, 2019). Timers can be used to control dimming times and amplitudes around campus, reducing energy consumption at times of least use. Figure 13, adapted from a presentation at the 2015 Light Fair International Outdoor Lighting Control System Fundamentals, shows a proposal for the percentage of light emitted at different times of night, where 0% is lights off and 100% is full light emission (Wilbur & Poplawski, 2015). Having the lights dimmed at 50% or lower during the least occupied hours of the night helps to save electricity while still providing safe lighting conditions for motorists and pedestrians. Another type of distributed control system is motion sensing lighting. Although motion sensing systems could save on energy costs, their frequent activation could disturb livestock (Kyba, Hänel, & Hölker, 2014). The Head of the Dairy Department, Efstratios E. Souglis, stated that the farm animals have dim lights in their barns at almost all hours of the night, and changes to their lighting schedule could disturb the animals. Although the perimeter road on the east side of campus is distant from the livestock, the flickering lights from a motion sensor lighting system could disturb them. Centrally controlled lights that could be dimmed to reduce stress on the animals could be more suitable for the AFS.

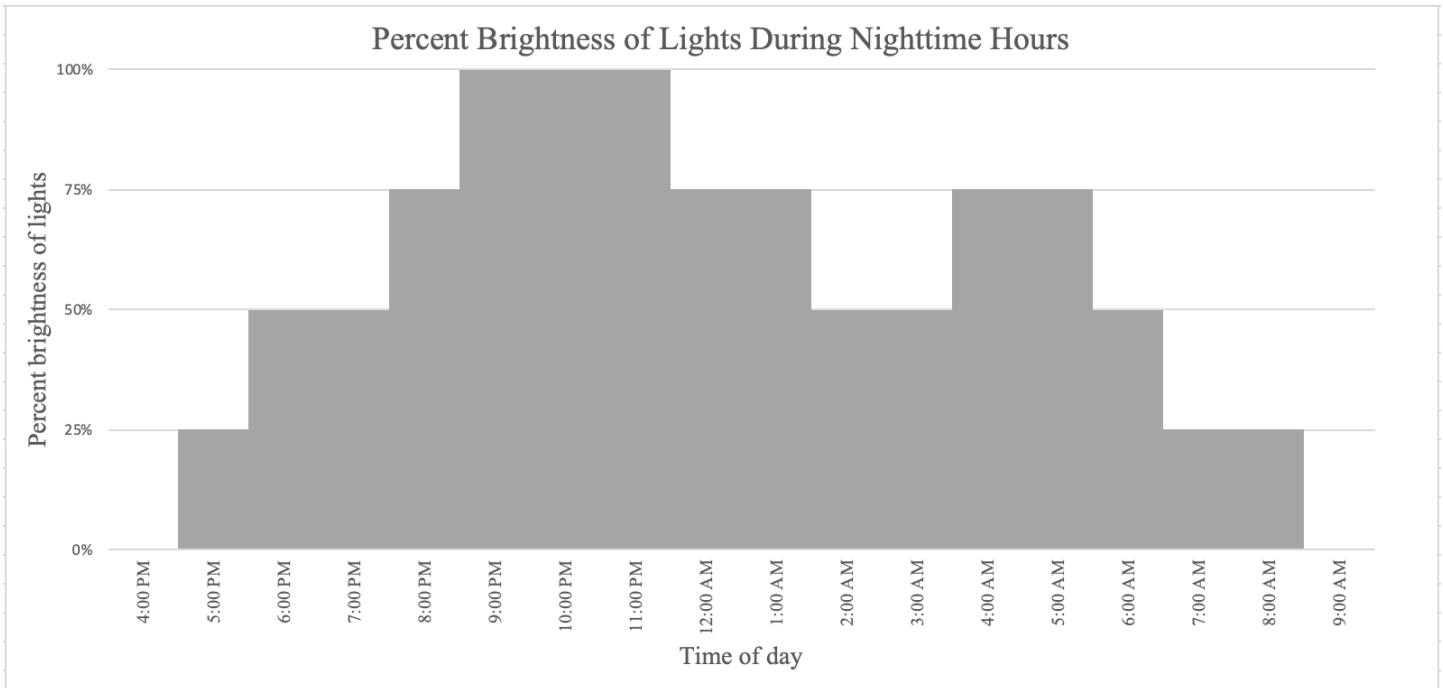


Figure 13: Recommended light dimming schedule to conserve electricity and limit light pollution

#### 4.2.2 Renewable energy technology system options

**Biogas digestion is not a suitable electricity generation source for powering the lights on the AFS campus.** Although biogas digesters have comparable cost per megawatt to solar PV technology, they have frequent and significant maintenance costs (Ghaem Sigarchian, Paleta, Malmquist, & Pina, 2015), (Indian Ministry of New and Renewable Energy, 2018), (KENBROOK SOLAR, 2019). Biogas digesters need operators to manage and oversee the system at all times, which is a specialized job with high labor costs (Jordan, 2019). Additionally, the combined heat and energy generation unit must be serviced every 2,000 and 20,000 operational hours and needs a full inspection for replacement every 60,000 operational hours (Akbulut, 2012). Since 50% of the energy produced by a biogas digester is in the form of heat, the operating costs of biogas digesters are only justified if the heat energy they produce can be used in addition to the electricity (Akbulut, 2012). Furthermore, to efficiently produce electricity from biogas digestion, the digester feed must be a combination of manure and organic material such as food waste. A farm of similar size to that of the AFS collects 20,000 tons of food waste for every 9,000 tons of manure (Jordan, 2019). According to an interview with the Buildings and Grounds Director of the AFS, the school does not produce enough organic waste to meet the needs of the biogas digester.

**Solar photovoltaic technology is a suitable renewable energy technology to power an outdoor lighting system at the AFS.** Table 6 compares solar PV technology to biogas digestion. As shown by Table 6, solar PV technology takes up less space, has lower maintenance costs, and



has a better environmental impact than biogas digestion, making it a more suitable energy generation option for the AFS. Many buildings on campus could house solar panels due to their positioning facing south, and the fact that their roofs are largely unused. Additionally, an outdoor lighting project could be expanded more easily than a biogas digestion tank as more needs, and funding sources arise. Due to the fact that solar panels can be implemented incrementally, they are a financially feasible technology to power an outdoor lighting system on campus.

Table 6: Comparison of solar photovoltaic technology and biogas digestion

Equivalent Energy Size Systems	Solar PV Technology	Biogas Digestion
Tangential benefits	Few	Many
Raw material availability	Plenty	Not enough
Space requirement	Minimal	Large
Upfront cost	Similar	Similar
Maintenance cost	Low or nothing	High
Environmental impact	Carbon negative	Carbon neutral

**Roof mounted solar panels are more suitable than ground mounted panels or stand-alone systems.**



Many other recent lighting projects have used stand-alone power systems. These systems require no additional infrastructure beyond the solar panel mounted light pole and storage battery, therefore saving money on installation costs and avoiding cables that could be vulnerable to the environment; however, batteries must be replaced frequently and cannot store large amounts of energy. Since standalone lights require constant and direct sunlight, they would not be suitable for the majority of paths on campus due to heavy tree cover (Bollinger, 2007). The Buildings and Grounds Director, Andonis Petras, expressed enthusiasm for the increased efficiency offered by ground-mounted panels. However, members of the senior farm staff, Efstratios E. Souglis, Stathis Yiannakis, and Yiannis Gatzolis, Heads of Dairy, Poultry, and Horticulture Departments, respectively, were enthusiastic about the idea of incorporating renewable energy technology onto campus but expressed reservations about ground solar panels. The urbanization of Thessaloniki has caused the limited cultivatable land space of the AFS to become increasingly valuable. Ground solar panels would have to take up some of this space. The Head of the Horticulture Department stated “Fields are sacred. I don’t want to plant anything on them besides plants to feed people and animals.” Through research, we found several advantages to



Figure 14: Roof mounted solar panels (top) compared to ground panels (bottom) (Gawrych, 2019)

roof mounted solar panels. They would be more visible to the AFS community on roofs as opposed to the far side of the farm near the manure lakes where they would be placed if the school pursued ground panels. Fortunately, many of the campus buildings already face south, and for the flat roofs, mountings could be constructed to slope panels at 30 degrees south to increase their efficiency (Solar Cells Hellas, 2009). Installation and maintenance costs for roof solar panel systems are considerably less than for ground panels as roofs provide existing infrastructure. Additionally, roof panels typically require little or no maintenance, whereas ground panels must be carefully monitored and groomed to make sure that nothing blocks their access to sunlight (Gawrych, 2019).

Table 7: Comparison of two of the highest value solar panels on the market (Wholesale Solar, 2019)

<b>Solar Panel Type</b>	 <b>ASTRONERGY</b>	 <b>MISSION SOLAR ENERGY</b>
<b>Wattage</b>	325	360
<b>Price per watt</b>	0.51 USD	0.68 USD
<b>Efficiency</b>	16.80%	18.36%
<b>Material</b>	polycrystalline	monocrystalline
<b>Warranty</b>	25 years	25 years
<b>Origin of Manufacture</b>	China/ Germany	United States of America

**High efficiency, low cost solar panels such as those produced by Astronergy or Mission Solar Energy could be suitable for the AFS.** From research on global solar panel manufacturers and their ratings, we identified two models that were of the greatest value. They are Astronergy 325 and Mission Solar 360. Table 7 compares these two panels. Both exhibit high efficiency at a low cost. The deciding factor for the AFS will likely be the origin country of the grant they receive for the solar panels. If the grant comes from European agencies, the Astronergy panels could be a viable option as the company has manufacturing facilities in Germany. However, because the United States government has funded many past projects at the AFS, we predict that this project will be funded by a USAID grant. In this case, the Mission Solar panels that are manufactured in the USA could be a good option to pursue (Wholesale Solar, 2019).

#### 4.2.3 Comparison of off-grid and on-grid electricity systems

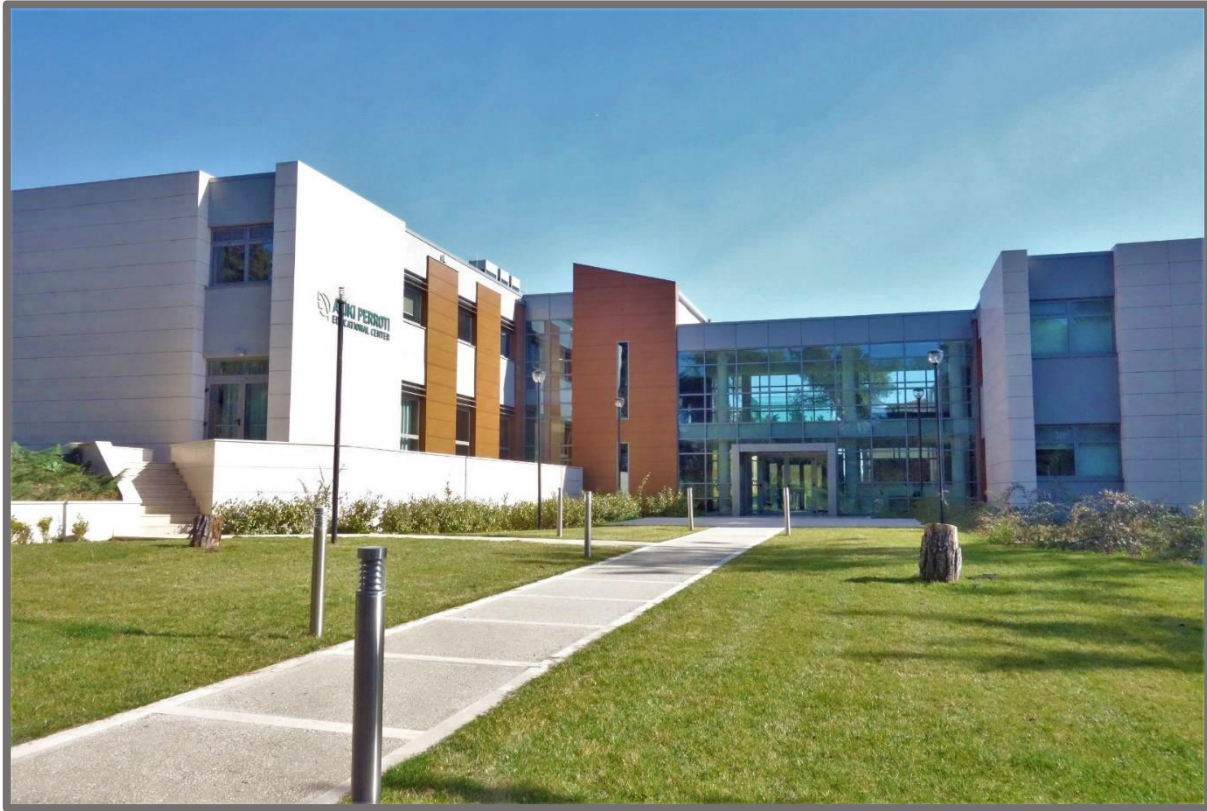
**The Wholesale Electricity Market currently requires that all independent electricity producers be connected to the grid and negotiate contracts with the Greek Public Power Corporation to sell and buy back electricity.** Permitting limitations due to the Greek Wholesale Electricity Market were reported to be a major concern of key stakeholders such

as the Buildings and Grounds Director of the AFS, Andonis Petras. Under current laws, the AFS would not be able to build an isolated renewable energy system that solely connects to their lights; the solar panels must also be connected to the national electricity grid, unless the AFS applies for special exemption (HERI Lawyer, 2019). To encourage renewable energy projects, the government established a Feed-in-Premium program to ensure that individual renewable energy producers earn back a minimum profit of 10% of their costs. However, in 2018, the European Union sued the Greek government for monopolizing the electricity market which was discouraging private renewable energy projects (Symeonides, 2019), (Andrianesis, Liberopoulos, & Biskas, 2011). Due to this, the Wholesale Electricity Market is being phased out of Greece starting at the beginning of 2019. Additionally, the Greek government must make strides to diversify the electricity market, specifically through renewable energy investment, starting in 2019 to comply with EU policies. Some programs have already been initiated to mitigate the monopoly, but due to changing policies, we cannot accurately predict what the grid connection requirements will be in the coming years.

**Based on current permitting policies requiring independent electricity producers to connect to the grid, a suitable contract for the AFS could be a net metering**

**agreement.** The Hellenic Electricity Distribution Network Operator (HEDNO) offers two kinds of contracts for systems of similar size to the proposed AFS lighting system. The first is a traditional feed-in system where the producer is paid for the electricity they produce. The second, newer option is a net metering agreement where the producer stores the electricity, they generate on HEDNO's grid. The producer is allowed free access to draw the amount of energy they produced from the grid for a limited time, typically approximately one year (PV Financing Consortium, 2019). This could allow for the excess energy generated by the PV system in the sunny summer days to help power the lighting during the longer winter nights, or during extended periods of cloudy weather (Maroulis, 2019). Since the lights will require regular electricity usage, a financially sensible option for a grid connected system could be the HEDNO net metering program.

**If laws are modified to make off-grid renewable energy systems more easily obtainable, this could be a suitable option for the AFS.** Grid connections require additional infrastructure and permitting costs. Additionally, they create safety hazards for maintenance workers who work on the grid (Kiefer TEK LTD, 2015). An independent system could reduce safety hazards and insulate the system from unreliability in the national grid. However, it would require more expensive batteries to store the electricity onsite. Currently, batteries represent approximately 90% of the material cost of a solar system, but the price of batteries has been steadily declining (Zart, 2017). For this analysis and the subsequent calculations, we will assume an off-grid system because on-grid contracts are negotiated and priced on a case-by-case basis, making on-grid costs difficult to estimate.



## 5.0 SYSTEM OPTIONS



In this section, we present system options to address lighting needs for different regions of campus and summarize their costs. First, we describe a pilot system that could be undertaken to jumpstart a renewable energy powered lighting project on the AFS campus. We then divide the campus roads into four zones as shown in Figure 15 based on needs identified by Dr. Vergos and Mr. Petras and specify lighting and energy requirements for each zone. Finally, we describe a system that addresses the areas of highest priority, based on the findings of this study.

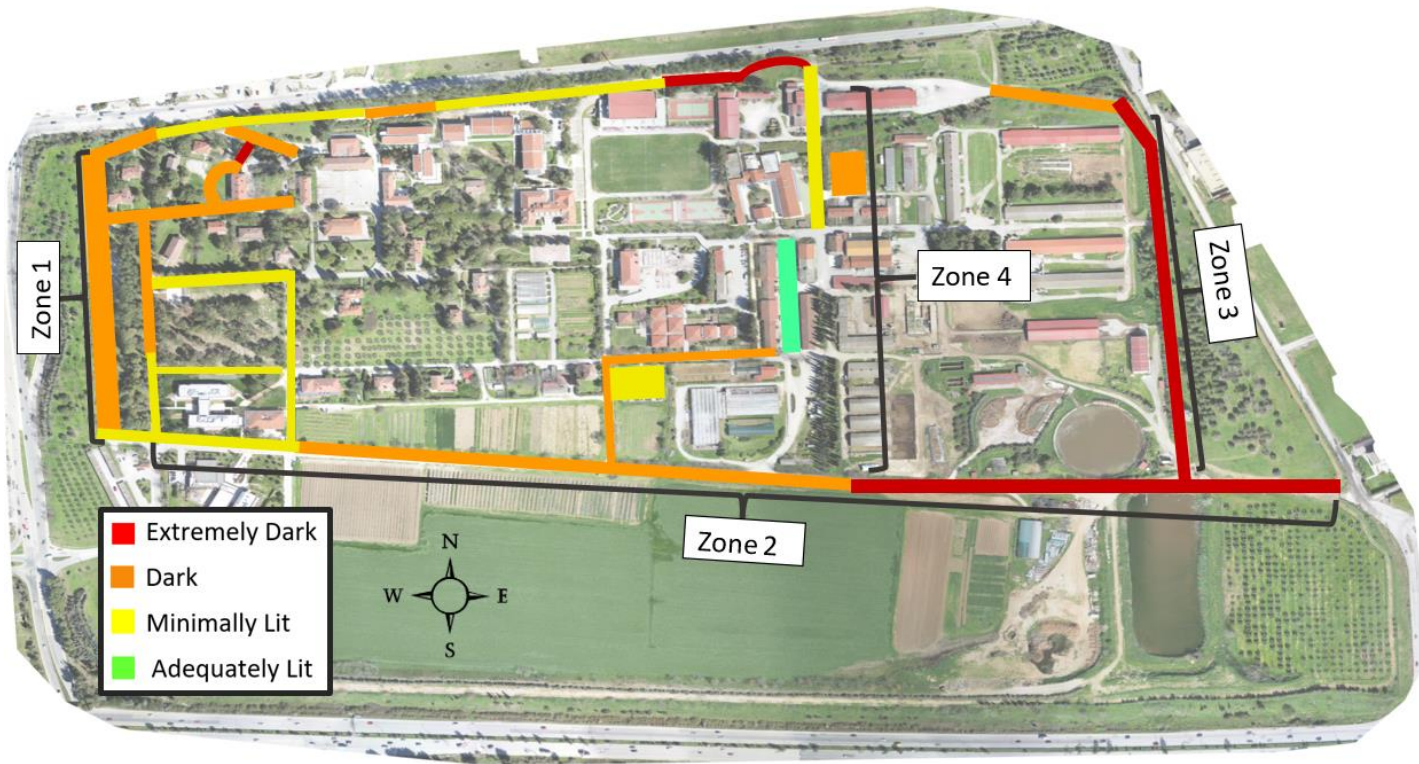


Figure 15: Map of the AFS campus describing the zones of priority for lighting and the levels of darkness

The roads were divided into different zones as follows:

**Pilot System:** Within the next year, AFS students studying landscaping will begin to redesign the high school courtyard to make it a social center for students. Currently, there are no outdoor lights in this area. To effectively illuminate the courtyard and transform it into a useable nighttime area, 10 lights would be needed, which would require only three solar panels to power them all night. These panels could ideally be placed on the roofs of the high school dormitories, which already host some solar panels for water heating purposes. The combined lighting-solar panel system would cost less than €38,000 total. Since this system has relatively low costs, it could be achieved in the short term without external funding and be the first implementation of a solar-lighting system on campus. Additionally, since the system could be located centrally and results could be visible, it could act as a demonstration site to gain support for an expanded renewable energy project on campus. If the system proves successful, it could serve as an



example in grant applications to expand the solar-lighting system on campus to other zones of priority.

Recommended System: We determined this zone to be the highest lighting priority based on direct observation of lighting conditions and from interviews with students and faculty about their most frequently travelled paths. Specifically, students identified the path connecting Perrotis College dormitory and the entrance to the public bus stop as regularly travelled. Additionally, students and staff indicated that the perimeter road from the high school dormitories to the Educational Vineyard has very poor lighting but also the most frequent vehicular traffic. 76 lights and 18 solar panels would be required to illuminate this zone. The total cost of the system would be €290,000 which is comparable in size to grants that the AFS has previously received.

Zone 1: This zone includes the roads that connect paths from Perrotis College dormitory and the AFS high school to academic buildings and the gate to the public bus station. This zone also the perimeter road from the front gate to the gymnasium. Lighting for this area would require 87 lights powered by 20 solar panels. The solar panels could be placed on the roofs of the high school and college dormitories. This unused space is flat, or at a slight angle of around 15°, which makes positioning the panels much easier as opposed to roofs oriented at steep angles. The cost of this system would be approximately €330,000 for the infrastructure, installation, labor, and maintenance for 25 years, of both the lighting and solar systems.

Zone 2: This zone consists of the perimeter road from the front gate to the east gate by the farm. Additionally, the parking lot and the roads adjoining it would be included. To illuminate this zone, 64 lights and 15 solar panels would be needed. The panels could be placed on the roofs of the Perrotis College dormitory. The cost of the system for this zone would be approximately €243,000.

Zone 3: In this zone, the perimeter road by the farm would be illuminated by 27 lights, powered by 6 solar panels. This zone is lower priority than zones 1 and 2 as it receives much less foot and vehicular traffic. However, there are still many farm staff that would benefit from this increased lighting as they tend to animals at all hours of the night and day. According to the Head of the Dairy Department, the farm animals are far enough away from the road and would not be disturbed by the increased lighting. The solar panels could be placed on the roofs of the farm buildings, such as the milking barn, which has roofs with slight declines that are south-facing. The total cost of this system would be approximately €103,000.

Zone 4: Lastly, the roads extending from the perimeter road down toward the kindergarten and elementary school could be illuminated. This area receives high vehicular traffic in the morning and afternoon, as parents drop off and pick up their children, often in a rush, as described by the Head of the Horticulture Department. Four solar panels would be required to power 16 lights in this zone. The solar panels could be placed on the roofs of the high school dormitories. The total cost of the system in this zone would be approximately €62,500.

Total System: A combination of all four zones of priority, including the pilot system, would serve as a total comprehensive lighting solution for campus. This would consist of 194 lights powered by 45 solar panels. There is abundant space to house these solar panels on the school roofs as the high school dormitories alone have 100 m<sup>2</sup> of useable roof space, and the area needed for all 45 solar panels is only approximately 75 m<sup>2</sup>. The total cost of the system would be €740,000. Although the total system has a very large upfront cost, external grants could be utilized to fund the project. This system could gradually be constructed piece by piece to address one priority area at a time, as grants and resources become available.

Table 8 provides a general breakdown of the system requirements and costs. A more detailed version of this table can be found in Appendix D. The system calculation methods, details, and assumptions can be found in Appendix C.

*Table 8: Costs of lights and solar panels by priority zone*

	<b>Zone</b>						
	Pilot System	Recommended Area	1	2	3	4	Total
Length of road (m)	60	1371	1563	1151	488	296	3498
Number of lights required	10	76	87	64	27	16	194
One time costs of installation and lights	€ 35,600	€ 271,104	€ 309,127	€ 227,642	€ 96,516	€ 58,542	€ 691,827
Maintenance costs per every 25 years	€ 1,335	€ 10,166	€ 11,592	€ 8,537	€ 3,619	€ 2,195	€ 25,944
Wattage (kW)	0.2	1.523	1.737	1.279	0.542	0.329	3.887
Electricity cost per year	€ 162	€ 1,138	€ 1,298	€ 956	€ 405	€ 246	€ 2,904
Capital cost and installation of solar panels	€ 168	€ 1,178	€ 1,343	€ 989	€ 419	€ 254	€ 3,006
Space required (m <sup>2</sup> )	4.17	29.19	33.29	24.51	10.39	6.30	74.49
Number of solar panels needed	3	18	20	15	6	4	45
Battery and charge controller cost	€ 2,475	€ 17,342	€ 19,774	€ 14,562	€ 6,174	€ 3,745	€ 44,255
Inverter cost	€ 9	€ 68	€ 77	€ 57	€ 24	€ 15	€ 173
Total photovoltaic system cost	€ 2,652	€ 18,588	€ 21,195	€ 15,608	€ 6,617	€ 4,014	€ 47,434
Total cost of renewable energy lighting system	€ 38,252	€ 289,692	€ 330,321	€ 243,250	€ 103,133	€ 62,556	€ 739,261



## 6.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter summarizes the primary findings from this project and details technological and legal recommendations for initiating a renewable energy lighting project at the AFS. We describe methods for incrementally expanding the renewable energy-lighting system at the AFS to provide options for the school based on available funding and resources.

## 6.1 Summary of AFS needs, priorities, and resources

Inadequate lighting on campus poses a safety risk for both pedestrians and vehicles on the paths of shared use around campus. Specifically, the roads identified in Figure 16 are most in need of a more comprehensive outdoor lighting system. Renewable energy is a suitable solution to mitigate the ongoing electricity costs of the school, while making the campus a sustainable leader in the community and teaching their students about the benefits of environmental stewardship. The following list summarizes characteristics of a renewable energy lighting system identified through interviews with stakeholders on the AFS campus. The renewable energy powered lighting system must:

1. Provide enough light for pedestrians and motor vehicles to identify and avoid each other from a distance
2. Illuminate the dark paths on the western side of campus, specifically the path from the public bus stop access to the dormitories
3. Retain the natural ambiance of campus and be aesthetically pleasing by not over lighting
4. Be financially feasible through grants or other funding sources
5. Be safe, accessible, and visible so it can be utilized as an educational tool

Although this could be a project with high upfront costs and involve complicated legal procedures, the potential to improve road visibility, campus safety, and school sustainability could be significant long-term benefits. By developing a sustainably-powered lighting system, the AFS would not only be improving living conditions for the residents of campus, but they would



Figure 16: Recommended system for lighting on the AFS campus



be setting an example for their students and teaching the next generation the benefits of renewable energy technology.

## 6.2 Lighting choices

We recommend that the AFS invest in lamp fixtures with LED bulbs and full-cover shields in a centrally controlled system. The benefits of such a lighting system include:

- Increasing energy efficiency compared to traditional fixtures
- Minimizing costs of unnecessary lighting
- Reducing harmful effects of light pollution
- Directing projected lighting to a specified area
- Mitigating shadows, glare, and uneven lighting
- Preserving natural aesthetics while still providing adequate lighting
- Allowing for long distance, centralized control of total system
- Dimming of lights on a timer as needed.

## 6.3 Renewable energy choices

Roof-mounted solar panels are a suitable renewable energy technology to power the outdoor lighting system on the AFS campus. Solar energy technology capitalizes on the natural resources of the AFS, has low operational costs, and aligns with the school’s mission of educating its students in the “latest aspects of agriculture, ecology, and the life sciences, and to make Greece and its neighbors a better place” (American Farm School, 2019). A solar panel project with visible benefits would provide the campus and its community with a unique educational tool to learn about environmental conservation and the benefits of renewable energy technology.

The benefits of roof-mounted solar panels, in comparison to ground-mounted panels, are listed:

- Lower upfront costs
- Lower maintenance costs
- Lower operational costs
- Capitalize on unused space of roofs rather than cultivatable farm land
- Be located closer to student and life, where their benefits could more actively be appreciated

## 6.4 Grid connection

The pilot system should be pursued as an off-grid system because the scale of the project does not justify the potentially high, variable costs of a grid connection. Although batteries account for nearly 90% of the photovoltaic system, the process of obtaining a grid interconnection is laborious and expensive, especially considering the microscale of the pilot system. However, if the AFS decided to expand to the scale of the recommended system, we then suggest a grid



interconnection. At the scale of the recommended system, the costs of the batteries could outweigh the costs of an application for a net metering grid interconnection. The main benefit of a net metering agreement is being able to store excess energy in the grid with the option of drawing from it at any time during a period generally around one year.

## 6.5 Project scope

Although external funding and grants may be available to help with the upfront costs, a renewable energy and lighting system could be a large commitment for the AFS. Fortunately, solar PV systems have the ability to be expanded gradually as needs become prevalent and resources become available. We suggest that the AFS begin this process by starting with the pilot system described in chapter 5. Next, the AFS should add additional lighting to the areas specified in the recommended area specified in chapter 5. Finally, the AFS could expand to the total system. Table 9 shows the specific requirements of each system.

*Table 9: Overview of lighting and photovoltaic system requirements*

	Systems		
	Pilot	Recommended	Total
<b>Number of lights</b>	9	69	175
<b>Energy requirements per day (kWh/day)</b>	2.25	15.76	40.22
<b>Cost of lighting system (€)</b>	33,000	252,000	647,000
<b>Number of solar panels</b>	2	16	41
<b>Space required for solar panels (m<sup>2</sup>)</b>	3.75	26.27	67.05
<b>Cost of photovoltaic system (€) *</b>	2,500	17,000	43,000
<b>Total cost of system (€)</b>	34,500	261,000	665,000

*\*PV system costs based on off-grid costs as grid connection is variable for each individual project*

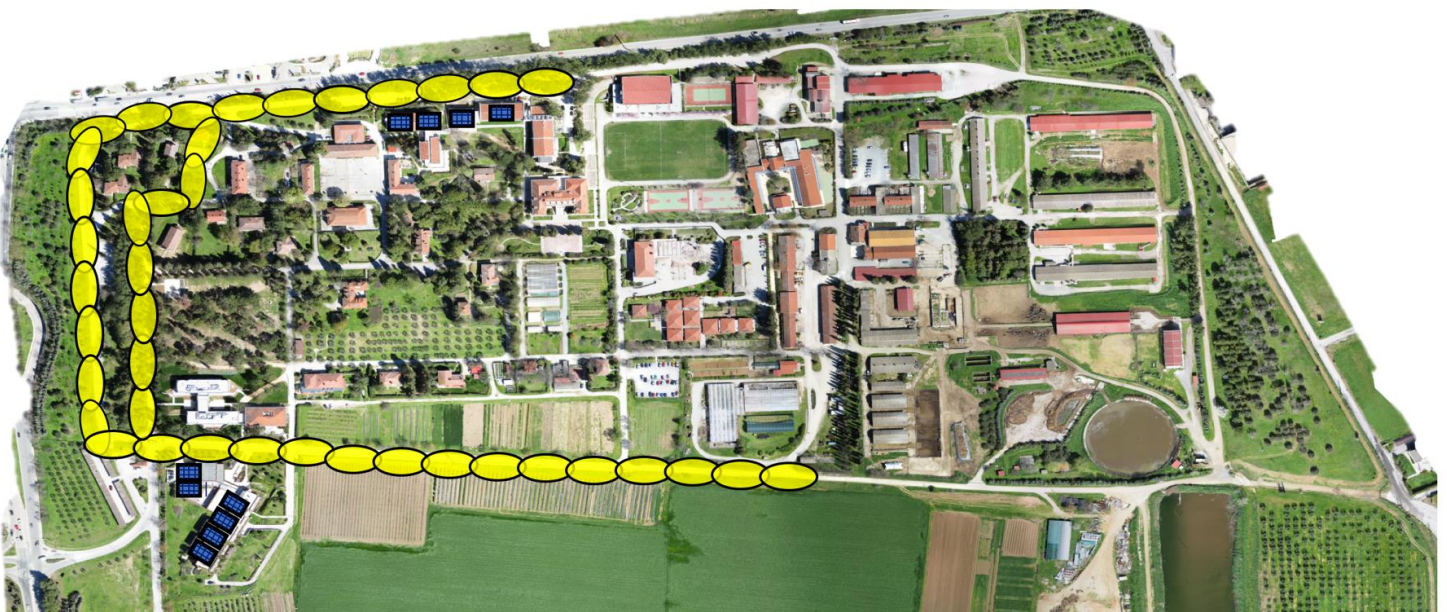
The AFS could begin with a small, off-grid pilot system to showcase the benefits of renewable energy on campus. A low cost pilot system could provide justification for a larger system, providing experience for future projects and a useful example with which to secure grant

funding. Figure 17 shows the location of the lights and the panels that could power a pilot system.



*Figure 17: Map of lights and solar panels for pilot system*

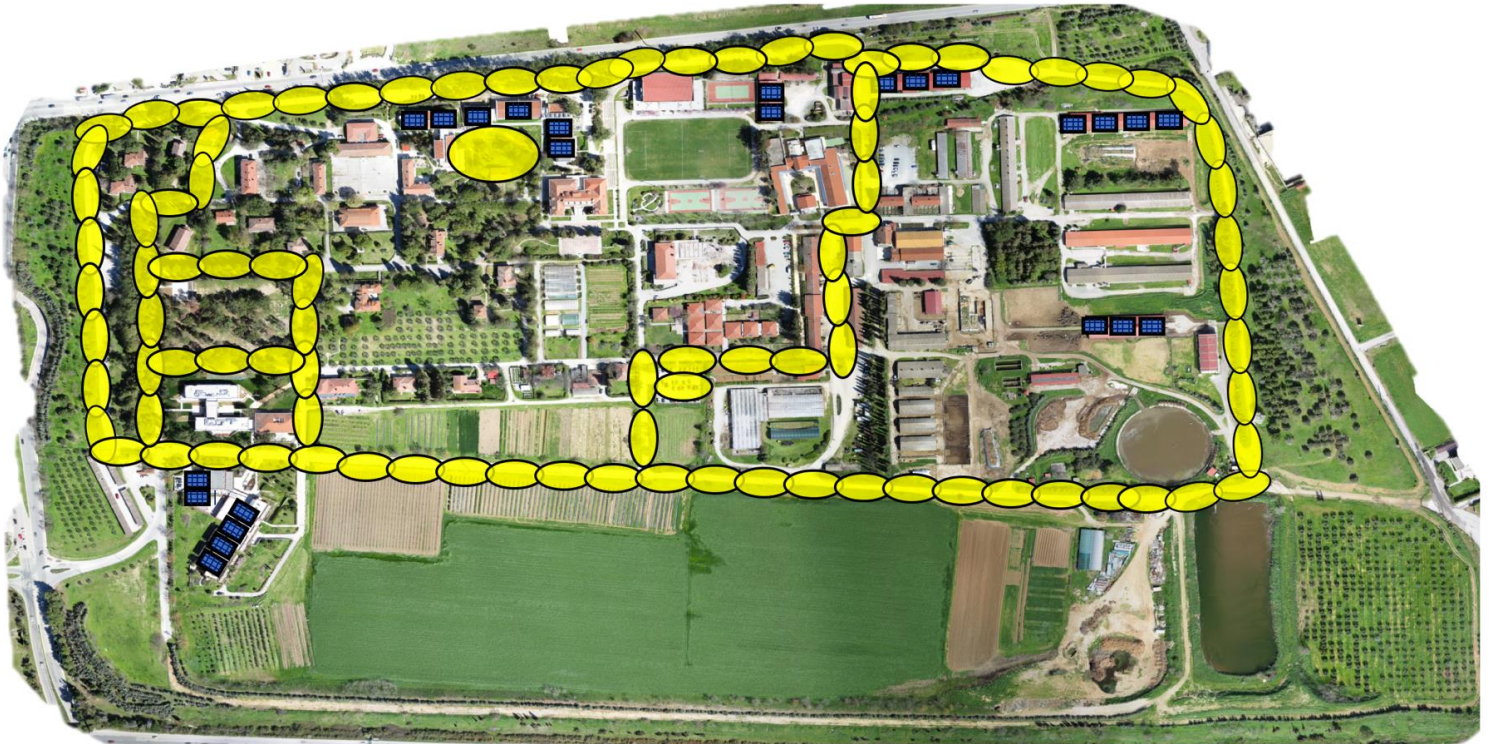
From the pilot program the next step could be an expansion of the system until it illuminates the whole of the recommended area. This could generate the greatest benefit to campus as the most traveled areas become more usable. The specific placement and location of the lights and solar panels can be seen in Figure 18.



*Figure 18: Map of lights and solar panels for recommended system*



As funding and resources become available, the system could be gradually expanded piece by piece to cover all the paths and roads on campus that could benefit from additional lighting. Figure 19 shows the proposed power and lighting system for the total system.



*Figure 19: Map of lights and solar panels for total system*

This report has described how a solar powered lighting system could economically improve the road visibility and sustainability of the AFS campus. It is our hope that the AFS will be able to use the recommendations from this report to improve the safety of the campus while simultaneously creating an educational tool to bring awareness to students and the community about renewable energy technology, helping the next generation to become more environmentally conscientious.

# BIBLIOGRAPHY

- Akbulut, A. (2012). Techno-economic analysis of electricity and heat generation from farm-scale biogas plant: Çiçekdağı case study. *Energy*, 44(1), 381–390.  
<https://doi.org/10.1016/j.energy.2012.06.017>
- American Biogas Council. (2019). American Biogas Council. Retrieved January 31, 2019, from <http://americanbiogascouncil.org/index.asp>
- American Farm School. (1982). *Annual Institutional Report to the Agency for International Development for the Calendar Year 1982*.
- American Farm School. (1983). *Annual Institutional Report to the Agency for International Development for the Calendar Year 1983: Creation of Alternate Energy Center*.
- American Farm School. (1989). *Agency for International Development American Schools and Hospitals Abroad Application for Assistance 1989*.
- American Farm School. (1991). *Agency for International Development American Schools and Hospitals Abroad Application for Assistance 1991*.
- American Farm School. (2019). *American Farm School Annual Report 2018* [Annual Report]. Retrieved from The American Farm School website: <https://www.afs.edu.gr/annual-report/>
- Andrianesis, P., Liberopoulos, G., & Biskas, P. (2011). An overview of Greece's wholesale electricity market with emphasis on ancillary services. *Electric Power Systems Research*. Retrieved from DOI: 10.1016/j.epsr.2011.04.005
- Assimakis, D., & Kitsilis, M. (2016). Law 4414/2016: A new support scheme for renewable electricity in Greece. Retrieved January 30, 2019, from

<http://www.nortonrosefulbright.com/knowledge/publications/143555/law-44142016-a-new-support-scheme-for-renewable-electricity-in-greece>

Atlas Energy Storage Systems. (2019). Features | Atlas Energy Storage Systems - Lithium Batteries for Off-Grid Storage. Retrieved April 18, 2019, from atlas-ess website: <https://www.atlas-ess.com/features>

Atlas Solar Innovations. (2019). Pickrell Solar Contractors - Installation and Repair of Solar Panels in Pickrell NE. Retrieved April 18, 2019, from <https://atlassolarinnovations.com/solar-pickrell-specialists>

Bollinger, J. D. (2007). *Applications of solar energy to power stand-alone area and street lighting*. 102.

Boomsma, C., & Steg, L. (2014). Feeling Safe in the Dark. *Environment and Behavior*, 46 (2), 193–212. <https://doi.org/10.1177/0013916512453838>

Changalov, K. (2013, May). Shakopee High School Brings Learning to the Outdoors Utilizing Renewable Energy | Clean Energy Resource Teams. Retrieved February 13, 2019, from <https://www.cleanenergyresourceteams.org/publication/shakopee-high-school-brings-learning-outdoors-utilizing-renewable-energy>

City of Toronto. (2017). *Best Practices for Effective Lighting*. 82.

Commonwealth Court of Pennsylvania. *Mary Ann SNYDER and Robert Snyder, her husband, Appellees, v. NORTH ALLEGHENY SCHOOL DISTRICT, Appellant.* , No. 95–2476 (Commonwealth Court of Pennsylvania 1998).

Covenant of Mayors for Climate & Energy. (2016). Financing Opportunities for Local Climate & Energy Actions. Retrieved April 18, 2019, from <https://www.eumayors.eu/en/>



- Crabb, G. I., & Crinson, L. (2009). *The Impact of Street Lighting on Night-Time Road Casualties*. 16.
- CREE. (2019). LED Street Lights & Street Bulbs | Cree Lighting. Retrieved April 3, 2019, from <https://lighting.cree.com/products/outdoor/street-and-roadway/xsp-series-1>
- Crist, R. (2018, February 24). These LED bulbs offer 100 watts worth of light: Which is best? Retrieved April 5, 2019, from CNET website: <https://www.cnet.com/news/best-100w-led-light-bulbs/>
- Eunice Energy Group. (2018). Company – Eunice Energy Group. Retrieved January 30, 2019, from <http://eunice-group.com/company/>
- European Commission. (2016). Europe 2020 strategy [Text]. Retrieved April 18, 2019, from European Commission - European Commission website: [https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy\\_en](https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_en)
- Falchi, F., Cinzano, P., Elvidge, C. D., Keith, D. M., & Haim, A. (2011). Limiting the impact of light pollution on human health, environment and stellar visibility. *Journal of Environmental Management*, 92(10), 2714–2722. <https://doi.org/10.1016/j.jenvman.2011.06.029>
- Fennelly, L., & Perry, M. (2014). *The Handbook for School Safety and Security: Best Practices and Procedures*. Butterworth-Heinemann.
- Flagstaff Zoning Board. (2017). *Division 10-50.70: Outdoor Lighting Standards*. Retrieved from [https://flagstaff.az.gov/DocumentCenter/View/14707/Chap10-50\\_SupplementaltoZones\\_Part2\\_Nov1?bidId=](https://flagstaff.az.gov/DocumentCenter/View/14707/Chap10-50_SupplementaltoZones_Part2_Nov1?bidId=)

- Gawrych, D. (2019). *Interview with EnergyMonster, a solar panel manufacturer* (S. Fitzpatrick, Interviewer).
- Getu, B. N., & Attia, H. A. (2016a). *Electricity Audit and Reduction of Consumption: Campus Case Study*. *11*(6), 5.
- Getu, B. N., & Attia, H. A. (2016b). *Electricity Audit and Reduction of Consumption: Campus Case Study*. *11*(6), 5.
- Ghaem Sigarchian, S., Paleta, R., Malmquist, A., & Pina, A. (2015). Feasibility study of using a biogas engine as backup in a decentralized hybrid (PV/wind/battery) power generation system – Case study Kenya. *Energy*, *90*, 1830–1841.  
<https://doi.org/10.1016/j.energy.2015.07.008>
- Greece electricity prices, June 2018 | GlobalPetrolPrices.com. (2019). Retrieved April 3, 2019, from GlobalPetrpPrices.com website:  
[https://www.globalpetrolprices.com/Greece/electricity\\_prices/](https://www.globalpetrolprices.com/Greece/electricity_prices/)
- HERI Lawyer. (2019). *Phone Interview with Hellenic Energy Regulation Institute*.
- Hirtenstein, A., & Tugwell, P. (2018, May 1). Greece Kicks Off \$3.6 Billion Program for Solar, Wind Projects. Retrieved January 28, 2019, from Renewable Energy World website:  
<https://www.renewableenergyworld.com/articles/2018/05/greece-kicks-off-3-6-billion-program-for-solar-wind-projects.html>
- IDEO. (2015). Design Kit: The Human-Centered Design Toolkit. Retrieved February 17, 2019, from <https://www.ideo.com/post/design-kit>
- Indian Ministry of New and Renewable Energy. (2018). FAQs. Retrieved April 16, 2019, from [https://mnre.gov.in/file-manager/UserFiles/faq\\_biomass.htm](https://mnre.gov.in/file-manager/UserFiles/faq_biomass.htm)

- International Dark Sky Association. (2019). Dark Sky Friendly Lighting. Retrieved April 3, 2019, from International Dark-Sky Association website: <https://www.darksky.org/our-work/lighting/lighting-for-industry/fsa/fsa-products/>
- International Energy Agency. (2011). Energy Policies of IEA Countries - Greece 2011 Review. *Energy Policies of IEA Countries*, 150.
- Jordan, R. (2019). *Interview with owner of Jordan's Dairy Farm* (M. Olson, Interviewer).
- Katsaprakakis, D. Al., & Zidianakis, G. (2017). Upgrading Energy Efficiency For School Buildings In Greece. *Procedia Environmental Sciences*, 38, 248–255. <https://doi.org/10.1016/j.proenv.2017.03.067>
- KENBROOK SOLAR. (2019). Solar Power Plant Details & Price 1kW-1mW. Retrieved April 16, 2019, from <https://kenbrooksolar.com/solar-power-plants/mw-solar-power-grid>
- Kiefer TEK LTD. (2015). NET METERING | Kiefer. Retrieved April 8, 2019, from <http://kiefer.gr/services/%ce%bdet-metering/>
- Kula, D. (2019). LED Cost for Street Lights (Revised 2019). Retrieved April 3, 2019, from MyLEDLightingGuide website: <https://www.myledlightingguide.com/blog-the-cost-of-street-lights>
- Kyba, C. C., Hänel, A., & Hölker, F. (2014). Redefining efficiency for outdoor lighting. *Energy & Environmental Science*, 7(6), 1806–1809. <https://doi.org/10.1039/C4EE00566J>
- MacArther, E. (2017). Case Studies: Closing the Nutrient Loop. Retrieved March 29, 2019, from <https://www.ellenmacarthurfoundation.org/case-studies/closing-the-nutrient-loop>
- Marder. (2004). *Stewards of the Land*.
- Maroulis, G. (2019, January 17). single. Retrieved April 8, 2019, from <http://www.res-legal.eu/search-by-country/greece/single/>

- McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature*, 517, 187.
- OECD. (2019a). Energy - Primary energy supply - OECD Data. Retrieved April 18, 2019, from OECD.org website: <http://data.oecd.org/energy/primary-energy-supply.htm>
- OECD. (2019b). Unemployment - Unemployment rate - OECD Data. Retrieved April 18, 2019, from OECD.org website: <http://data.oecd.org/unemp/unemployment-rate.htm>
- OSRAM. (2019). *Street Light Control | Light is OSRAM*. Retrieved from <https://www.osram.com/ds/knowledge/street-light-control-by-osram-innovative-light-management-system-for-outdoor-areas/index.jsp>
- Philips. (2019). SON SON High Pressure Sodium High Intensity Discharge Lamps. Retrieved April 5, 2019, from Philips Lighting website: <http://www.lighting.philips.com/main/prof/conventional-lamps-and-tubes/high-intensity-discharge-lamps/son-high-pressure-sodium/son>
- PV Financing Consortium. (2019). Greece, Residential Systems, Self consumption scheme (based on net-metering), Grid Connection Permit. Retrieved April 17, 2019, from <http://database.pv-financing.eu/en/database/pvgrid/greece/national-profile-8/residential-systems/2437/programme-for-solar-rooftop-systems-fit-1/grid-connection-permit-4.html>
- Radetsky, L. (2011). Streetlights for Local Roads. *National Lighting Product Information Program*, 14, 28.
- Skandali, C., & Lambiri, Y. S. (2018). Optimization Of Urban Street Lighting Conditions Focusing On Energy Saving, Safety And Users' Needs. *International Journal of Contemporary Urban Affairs*, 2(3), 112–121. <https://doi.org/10.25034/ijcua.2018.4726>

Solar Cells Hellas. (2009). Solar Cells Hellas. Retrieved March 29, 2019, from

<http://www.schellas.gr/en/categories.asp?catid=90>

Solar Power System Cost Data for recent installations. (n.d.). Retrieved April 3, 2019, from

<https://www.solarreviews.com/solar-power-system>

[cost/?ssi\\_sortby=pricelth&ssi\\_stateabbr=&ssi\\_panel\\_brand=&ssi\\_inverter\\_brand=1439&ssi\\_systemsize=&ssi\\_cityname=&ssi\\_locationtype=statecity&ssi\\_zipcode=&action=Search&ssi\\_sortby\\_override=pricelth](https://www.solarreviews.com/solar-power-system-cost/?ssi_sortby=pricelth&ssi_stateabbr=&ssi_panel_brand=&ssi_inverter_brand=1439&ssi_systemsize=&ssi_cityname=&ssi_locationtype=statecity&ssi_zipcode=&action=Search&ssi_sortby_override=pricelth)

Stolaki, S. N., Kazadzis, S. A., Foris, D. V., & Karacostas, Th. S. (2009). Fog characteristics at

the airport of Thessaloniki, Greece. *Natural Hazards and Earth System Science*, 9(5),

1541–1549. <https://doi.org/10.5194/nhess-9-1541-2009>

Sunrise and sunset times in Thessaloniki. (2019). Retrieved April 3, 2019, from

<https://www.timeanddate.com/sun/greece/thessaloniki>

Symeonides, M. (2019, March 5). Electricity - GREEK LAW DIGEST The Official Guide to

Greek Law. Retrieved April 8, 2019, from <http://www.greeklawdigest.gr/topics/energy-minerals/item/91-electricity>

Traverso, M., Donatello, S., Moons, H., Rodriguez, R., Caldas, M. G., Tichelen, P. V., ...

Geerken, T. (2017). Revision of the EU Green Public Procurement Criteria for Street Lighting and Traffic Signals. *CEN*, 138.

USAID. (2018, August 31). Grant and Contract Process | Work With USAID | U.S. Agency for

International Development. Retrieved March 20, 2019, from

<https://www.usaid.gov/work-usaid/get-grant-or-contract/grant-and-contract-process>

Vergos, E. (2019). *Interview with Dr. Evangelos Vergos* (S. Fitzpatrick, Interviewer).



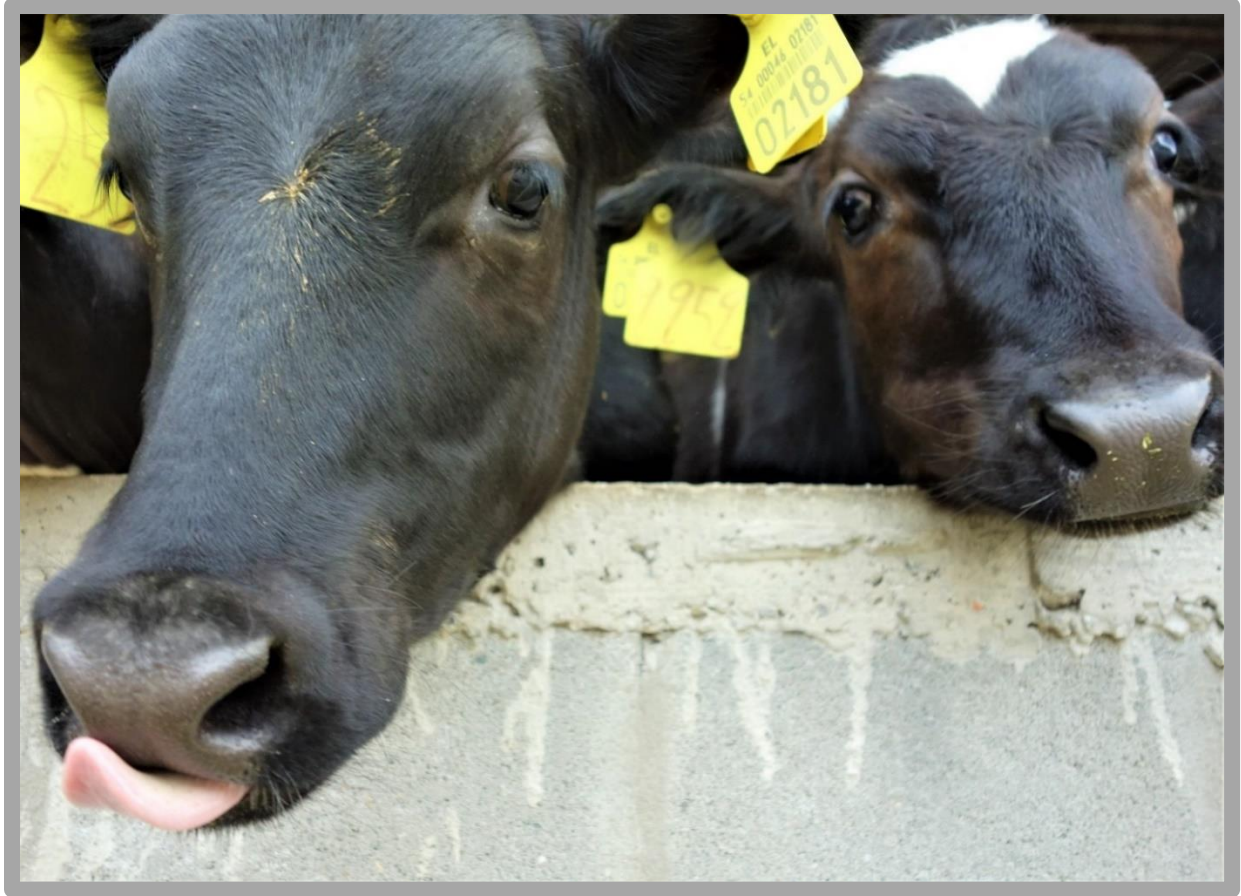
Weather Atlas. (2019). Thessaloniki, Greece - Detailed climate information and monthly weather forecast. Retrieved April 4, 2019, from Weather Atlas website: <https://www.weather-atlas.com/en/greece/thessaloniki-climate>

Wholesale Solar. (2019). Solar Panel Guide. Retrieved from Wholesale Solar website: [https://www.wholesalesolar.co/hubfs/ebooks/solar-panel-guide/solar-panel-guide.pdf?utm\\_campaign=LM%20-%20Solar%20Panels&utm\\_source=hs\\_automation&utm\\_medium=email&utm\\_content=68393412&\\_hsenc=p2ANqtz-8US\\_CypO3gszbCXwIoRd6ZNP6POKwN0M04FgZPX4\\_2LiEgXq8HOY-6-t91UpTzkFDxtVccF4NDXgezvr2irH9CHIBapA&\\_hsmi=68393412](https://www.wholesalesolar.co/hubfs/ebooks/solar-panel-guide/solar-panel-guide.pdf?utm_campaign=LM%20-%20Solar%20Panels&utm_source=hs_automation&utm_medium=email&utm_content=68393412&_hsenc=p2ANqtz-8US_CypO3gszbCXwIoRd6ZNP6POKwN0M04FgZPX4_2LiEgXq8HOY-6-t91UpTzkFDxtVccF4NDXgezvr2irH9CHIBapA&_hsmi=68393412)

Wilbur, M., & Poplawski, M. (2015, May). *Outdoor Lighting Control System Fundamentals*. Presented at the Light Fair International 2015. Retrieved from [https://www.energy.gov/sites/prod/files/2015/09/f26/outdoor-lighting-control-system-fundamentals\\_1.pdf](https://www.energy.gov/sites/prod/files/2015/09/f26/outdoor-lighting-control-system-fundamentals_1.pdf)

Yannis, G., Kondyli, A., & Mitzalis, N. (2013). Effect of lighting on frequency and severity of road accidents. *Institution of Civil Engineers*, 166(TR5), 271–281.

Zart, N. (2017, December 11). Batteries Keep On Getting Cheaper. Retrieved April 16, 2019, from CleanTechnica website: <https://cleantechnica.com/2017/12/11/batteries-keep-getting-cheaper/>



# APPENDICES

## Appendix A: Next steps

After the system pilot system has proven successful, we suggest the AFS continue with the following steps to expand their solar and lighting system:

- Contact outdoor lighting manufacturer such as Zincometal<sup>4</sup>
  - Receive cost estimate for project scale
- Contact solar PV manufacturer
  - Receive cost estimate for project and energy scale
- Apply for grants using cost estimates from lighting and solar manufacturers
  - Two promising options based on this research are listed in Table 10.

*Table 10: Details of two potential funding sources*

Funding Source	Total funds available	Award amount	Relevant Funding Priorities
<b>USAID- American Schools and Hospitals Abroad</b>	\$23 million	\$500,000- \$2,000,000	International schools that are teaching American ideals, helping to encourage growing societies
<b>EU LIFE Program</b>	€3.4 billion	€500,000- €1.5 million	Environment and resource efficiency, climate change mitigation and adaptation

- Enter into a net metering agreement with HEDNO by completing the following steps:
  - Submit interconnection application
  - Submit Convention application (with payment) and accept interconnection offer
  - Approve connection contract (with payment)
  - Submit and approve netting agreement
  - Construct actual PV system on site
  - Submit connection activation application
  - Activate connection

The last stage of fully realizing the benefits of a renewable energy system would be to integrate the renewable energy technology into the curriculum as an educational tool to empower students to become more mindful and environmentally conscientious, and to realize the impact of their individual participation in sustainable acts.

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<sup>4</sup> Zincometal is an outdoor lighting installation company located near Thessaloniki. Through research, we spoke to them to understand different lighting options and they expressed interest, knowledge, and competency in further pursuing a lighting improvement project at the AFS.

## Appendix B: Interview responses

### Appendix B1: Andonis Petras, Buildings and Grounds Director (April 8, 2019)

**1. How much money does the school spend to power the outdoor lighting on campus?**

His secretary sent us the electricity bill data. However, it was the total electricity uses and costs per month for the entirety of the campus. They do not have specific metering data on different substations.

**2. How long do the outdoor lights operate for? (specifically, the sports fields)**

The lights operate all night. There are very few, but some have been upgraded to LED lights. The electricity costs are very high because students keep their lights on all night even though they are encouraged not to.

**3. How frequent/severe are safety breaches on campus?**

Not very severe or frequent. Lights would have no impact on this.

**4. What do you think could be done to reduce these occurrences?**

N/A

**5. Where have they occurred and why do you think these locations were targeted?**

N/A

**6. How do you think increased lighting would impact campus safety?**

They are doing their best to try to separate walking and driving paths. Both paths need more lights. Dorms have safety lights already because of Greek and EU rules and laws for lighting for permits for safety, fire protection, earthquake safety. Lights would help to make campus more walkable and useable by students and residents. Want to keep cars on the perimeter road as much as possible.

**7. How do you think increased lighting would impact road safety on campus?**

Trying to limit car access on campus as much as possible, perimeter roads if anything. Some cars need to go in middle of campus to residential buildings though.

**8. How much funding is available for a lighting/renewable energy project?**

3-4 roofs on buildings on campus are currently being used to collect and reuse water runoff. Currently a centralized system of electrical current, 3 substations of electricity. create PV power and distribute energy to different substations. aesthetic concerns of solar on roofs. Stringent permitting process for electrical authority, Greek government, and the EU. Must sell the electricity to the authority, need new network to send electricity back to grid. Can't do a closed system, have to sell it to government and then buy it back. New substation for Alkali Perrotis costed 35,000 Euros just for permits. authority makes money off of this.

**9. Where, and how much space is available for solar panels? (Divide the space by building)**

Don't know how much roof space. He didn't really like the idea of roof panels aesthetically or logistically. Didn't seem to understand that solar panels on roofs would be used to power a different system other than the buildings.

**10. How much physical space is available on the farm for a bio digester?**

Not interested in pursuing this option.

**11. How much animal waste is used purposes and how much in wasted?**

All the animal waste is used to irrigate the fields. Solid waste is used for compost on fields and excess is given to other producers. Unclear if it is sold or gifted. Mixing different kinds of animal wastes is difficult as they have different properties which must be treated differently. For a biogas, they would need different tanks to process. Need big quantity of waste to make successful (i.e. Jordans).

**12. For dining services, how much food waste is produced and what is currently being done with it?**

In the school's contract with food services, the company is responsible for disposing of the food waste. They have a 6-year contract with the school that has 3 years left. But, it is a difficult process to renegotiate this.

**13. Have you had any issues with lights or cables being damaged by weather or other environmental dangers?**

As a structural engineer, he has worked on designing buildings to be resistant to earthquakes and other environmental factors. The same would go into a new lighting system. Not a concern.

## Appendix B2: Anna Papakonstantinou Deputy Director of the Junior College (March 28, 2019)

### 1. Do you live on campus?

Yes. Was born here and resided on campus for 25 years, left in 2001 but still works here.

#### a. Do you walk around campus at night? How safe do you feel doing so?

Yes, feels very safe, brings her kids with her at night with no concerns

##### i. Which paths do you take most frequently?

Mostly just takes route from Princeton Hall, where she works, to the parking lot and then the perimeter road to drive to and from the parking lot.

##### ii. Which areas (if any) do you avoid?

She chooses to avoid the farm at night. Since it is very dark down there and close to the border, “you never know what is down there,” so she thinks it’s better to stay away. She doesn’t have much of a reason to go down there anyways.

### 2. If money and resources were no object, what do you wish could be done to improve security on campus?

She believes security cameras and additional lighting would help her feelings of safety.

### 3. What do you think will be the impact of more lighting on campus?

Increasing the lighting on campus would make her feel more secure. It would also help her to know where she is going better because it is so dark and navigating in the dark is difficult.

### 4. Do you teach about climate change and/or environmental topics?

Used to teach agronomy but hasn’t been teaching for 17 years. Back then she taught about sustainable farming but not much.

#### a. What is your curriculum for teaching about climate change and environmental topics?

She believes farmers have a big impact on the environment and thinks especially now, that sustainable farming needs to be a more heavily discussed topic.



**5. What do you think the impact would be of having renewable energy projects on the campus?**

If it had obvious results, many students would want to incorporate it onto their own farms after graduating. Believes it would most likely interest students after graduation when they looking to cut costs on their own farms; however, it is person by person basis. Younger farmers are more likely to adapt to this idea than traditionalist older farmers. Older farmers may be more inclined to use renewable energy if the younger generation made it appear more desirable.

**6. Do you have interest in teaching more about renewable energy and climate change?**

N/A

**7. How knowledgeable are students about environmental issues and/or renewable energy?**

She said that students “are probably not aware how close they are to the problem and don’t understand how individuals cause or can help the problem”. Since she isn’t teaching anymore, she doesn’t have an accurate idea about their knowledge levels.

**8. Are there any vocational programs that could incorporate a renewable energy project into their curriculum?**

N/A

**9. How could you use a renewable energy system outside of the classroom? i.e. an extracurricular activity or post-graduation example.**

Students probably won’t want to participate in extra work outside the classroom, but she believes it would be worth trying because there will be some students that will want to!

**Appendix B3: Konstantinos Zoukidis adjunct lecturer and researcher (March 28, 2019)**

**1. Do you live on campus?**

no

**a. Do you walk around campus at night? How safe do you feel doing so?**

Leaves campus after work around 21:00, but also tends to the farm at very early hours of the morning before the sun is even up. He feels very safe doing so and has never had any safety concerns.

**i. Which paths do you take most frequently?**

Takes car route all around perimeter of campus. Walks from academic buildings to parking lot and to the farm.

**ii. Which areas (if any) do you avoid?**

He avoids no areas.

**2. If money/resources are no object, what do you wish the administration would do to improve your feelings of safety?**

Additional security at the gate would help his feelings of safety. There currently are rules about who can enter the gate and at what times, but the rules aren't necessarily enforced. Having security guards doing walking patrols would also help.

**3. What do you think will be the impact of more lighting on campus?**

The road near the farm could use more lights for walking purposes and navigation. The greenhouse areas also have no lights, so it is hard to tend to plants and animals when it is dark before the sun comes up.

**4. Do you drive on campus? How safe do you feel doing so?**

Yes, he drives at night.

**a. Have you ever experienced any interactions with pedestrians in the road at night?**

Drivers on campus know that students will be walking around so they drive cautiously and slowly. He acknowledged that this is not that case off campus though.

**5. Do you teach about climate change and/or environmental topics?**

Yes, in soil science and in general courses like environmental technology.

**a. What is your curriculum for teaching about climate change and environmental topics?**

Students have a very limited understanding of the concepts and he believes they could benefit from more environmental concepts in the curriculum.

**6. What do you think the impact would be of having renewable energy projects on the campus?**

He would like to teach more about environmental topics and use the project as a tool to interest and teach students more.

**7. Do you have interest in teaching more about renewable energy and climate change?**

Yes, see answer above.

**8. How knowledgeable are students about environmental issues and/or renewable energy?**

Farmers families only care about money, not the environmental consequences or repercussions. More than 80% of the students come from farming families. He believes there needs to be a change in students' mindset for the concepts to follow through. However, he thinks that students are starting to see and understand the changes in the environment and the direction of new farming practices and techniques. He stated that the older generations only care about money, so if making a change to more environmentally conservative techniques saves money, they would be more interested. He also believes that younger generations have the power to change their parents' minds.

**9. How could you use a renewable energy system outside of the classroom? i.e. an extracurricular activity or post-graduation example**

For it to be seen as a success in the minds of students, need visibility and results over time. Students don't have much opportunity to experience benefits of renewable energy technology in their everyday lives.

**Appendix B4: Pantelis Hantzaras, Residence Life Coordinator (April 1, 2019)**

**1. Do you live on campus?**

Yes, has lived here for 13 years total. Used to be a student here and recalled that lighting used to be an issue then, too.

**a. Do you walk around campus at night? How safe do you feel doing so?**

Yes, feels 100% safe. There are some spots that are rather dark, but he never feels unsafe.

**i. Which paths do you take most frequently?**

\*Highlighted paths on map

**ii. Which areas (if any) do you avoid?**

He doesn't go near the farm at night because he doesn't want to disturb, he animals.

**2. If money and resources were no object, what do you wish could be done to improve security on campus?**

More lights would be helpful.

**3. What do you think will be the impact of more lighting on campus?**

The road near the farm could use more lights for walking purposes and navigation. The greenhouse areas also have no lights, so it is hard to tend to plants and animals when it is dark before the sun comes up.

**4. Do you drive on campus? How safe do you feel doing so?**

Yes, he has a hard time seeing students at night. On many roads, the only lights are from car headlights which is dangerous. Especially near the vineyard.

**a. Have you ever experienced any interactions with pedestrians in the road at night?**

There have been multiple incidents of close calls \*see map

**5. Do you think increased outdoor lighting would change student behavior?**

Yes, students may be inclined to go out more at night. Especially to and from the bus stop.

**6. Have you received any complaints from students about the campus at night?**

Highschool students have complained about the lack of lights before, but he has received no complaints from the Perrotis students.

**Appendix B5: Perrotis College students- collection of 14 responses (April 1-5, 2019)**

**1. Do you live on campus? If so, for how long?**

10 students live on campus, 4 do not.

**2. Did you grow up on a farm?**

4 students lived on a farm, 2 students grew up near farms, 8 did not grow up on farms

**3. Do you walk around campus at night? How safe do you feel doing so?**

All students, regardless of whether or not they walked around at night often, indicated that the AFS is a very safe campus and they never have any threats.

“Everyone knows everyone here. There are no strangers”.

**a. Which paths do you take most frequently?**

\*See Figure 8

**i. Which areas (if any) do you avoid at night and why?**

Many students indicated the farm as being a place that they avoid at night, mostly because it is dark and hard to navigate and that they don't have any reason to visit this part of campus at night. Some of the female students in particular mentioned that the paths near the church, the road near the bus stop, and the road behind the high school dorms are very dark and they try to avoid these areas at night, especially when they are alone.

**ii. How safe do you feel sharing the roads with cars at night? Do you have any concerns about your safety walking around at night? (Specifically, with cars)**

The majority of students indicated that they felt safe sharing the roads with cars because residents and faculty drive slow and safe on campus because there are so many students present. Many students also noted that there is usually a lack of cars on campus as it gets later at night. As long as you are aware of your surroundings and know where you are going, you should be fine, according to one student. Another student indicated the road near the bus stop is sometimes tricky and that cars drive fastest here.

**4. How do you see increased lighting impacting the campus?**

11 of the students said that increased outdoor lighting would have a positive impact on campus. Almost of the female students mentioned that it would increase their feelings of safety. 2 students expressed that they enjoy walking in the dark at night because of the feeling of connection to nature. 1 student was neutral. 83% of females said that more lighting was improve their feelings of safety. Only 9% of male students said that more lighting would increase their feelings of safety.

**5. Do you have interest in learning more about renewable energy and global warming?**

12 students expressed interest in learning more about both renewable energy and global warming. One student expressed no interest in either. Another student expressed interest only in global warming, but not renewable energy. The only classes that the students mentioned learning about global warming concepts was briefly in a first-year course.

**a. Do you think global warming is an issue in your life? On a global scale?**

All students believe global warming is an issue in their everyday life, but most all said that it is a bigger issue worldwide. Some students cited the extreme weather events around the world as indicators of this.

**b. Do you currently do anything in your everyday life to combat global warming?**

6 students said they either don't do anything to combat global warming, or that their actions have no impact. One student said, "I can't do anything to actively affect the world". Other students mentioned recycling, using less water, turning off lights when leaving the room, and public transportation as measures they take. Another common thread was that students have no faith that the government is making any efforts to help in the effort, so their actions don't really matter.



**c. Do you think a renewable energy project on campus could change your actions?**

A little less than half of the students expressed that it would make them more mindful and aware of their actions if they were able to see results and/or interact with the system. Of the students who said that it wouldn't change their actions, it was noted that one campus wouldn't make much of a difference in the bigger picture, so it wasn't necessarily worth the extra effort.

**d. Do you see yourself using renewable energy when you graduate?**

Of the students we asked this question, most of the answers were a tentative "yes", on the condition that money was a strong deciding factor in their decision.

**6. Would you be interested in working on building a renewable energy project?**

79% of the students expressed interest in helping with a project, and other 21% said that they wouldn't have enough time to dedicate to an extracurricular activity.

**7. Would you be interested in learning more about the benefits of renewable energy systems?**

100% of the interviewees desired more knowledge about renewable energy.

## **Appendix B6: Senior farm staff**

*Efstratios E. Souglis- Head of Dairy Department, Stathis Yiannakis- Head of Poultry Department, and Yiannis Gatzolis- Head of Horticulture Department (April 11, 2019)*

**1. Are you often at the farm when it is dark outside?**

Souglis: his staff begins milking cows at 2:30AM.

**3. What do you think would be the effect of increased lighting on the farm both for your safety and the animals?**

Souglis: dim lights are on for animals at most hours of the night on a fixed schedule

Gatzolis: humans need more lights

**4. How do you make sure your animals are safe at night?**

Gatzolis: chickens are indoors, cows are in borders, and there are people on the farm at almost all hours of the night. There are cameras and security patrols as well

**a. Have there been any security incidents on the farm in the last few years?**

Gatzolis: where there have been break ins on campus, the vandals usually enter campus through the east gate because it is dark and not very populated. They added cameras, but people can just go around them.

**b. How do you think safety could be improved?**

Gatzolis: less cameras, more walking patrols by security

**6. How is the waste used? How much of this is necessary for farm operation?**

Souglis: almost all of the animal waste is composted and used as fertilizer for the farm. It is a vital part of the farm's success.

Gatzolis: crop waste is tilled and goes back to nourish the farm land

**7. How much waste is discarded?**

Souglis: not much is wasted

Yiannis: not much is wasted

**8. Have you considered using renewable energy to offset energy needs?**

All: yes!

**a. Why or why not?**

Souglis: thinks it would benefit the farm and the whole rest of the school as well.

Very interested in solar panels for the roofs. "we already have roofs, we don't want anything on the farm", "only lazy famers put solar panels on their fields"

Yiannakis: the idea for biogas in the 80's was brilliant, but there was not enough money or technical expertise to keep it running

Gatzolis: has been pushing for it. Thinks the whole school should be using it. But, "I don't want to plant anything else on the fields besides plants to feed people and animals!", "Fields are sacred"

All: roof solar panels sound like a good idea for sure, but don't want to sacrifice valuable, usable farm land for a solar farm at all. Solar farms are out of the questions for them.

**9. Are you interested in learning more about renewable energy benefits?**

All: definitely! Specifically, how to use solar panels

**10. What do you think would be the effect of having a renewable energy project on campus?**

All: would be a very positive impact on the farm and on the campus as a whole. Want to help make it happen!

**10. Do you drive on campus? How safe do you feel doing so?**

Souglis: driving is very dangerous for both drivers and pedestrians, specifically the perimeter road

Gatzolis: Visibility is really poor on the roads, they are familiar with the conditions by now, so they drive with high caution. Especially as the campus has been growing, there have been more cars and more students on the road. "There are 15 mins in the morning and 15 mins in the afternoon when parents come to drop-off and pick-up their kids and they drive as if like they are still in the city"

## Appendix C: System calculation methods, details, and assumptions

### Appendix C1: Lighting specification assumptions and cost estimate calculations

In order to calculate the cost estimates for the lighting systems, we completed the following steps:

1. Measured distances of student and faculty identified priority roads using Google Maps, as shown in Appendix 3
2. Estimated each road and path to be 6m wide
3. Calculated lighted area by multiplying distances and width
  - a. For the pilot system, we used Google Maps to calculate area of the courtyard area
4. Used school safety standard from Illuminating Engineering Society of North America (IES) of 10 lux of light at street level (Fennelly & Perry, 2014)
5. Estimated 1200 lumens emitted per LED street light bulb (“LED Street Lights & Street Bulbs Cree Lighting”)
6. Assuming the light loss factor for LED street lights 4m in height is 0.9, we multiplied this by the lumens per light to determine the lumens needed at foot level (Radetsky, 2011)
7. Divided the lumens needed per foot level by the lux to determine the area that could be illuminated by one light, which was 108m<sup>2</sup>
8. Since the roads are assumed to be 6m in width, this is a distance of 18m between poles
9. Divided distances of roads and paths by 18m to determine number of lights
10. Estimated capital cost per lighting fixture to be €3550, including lighting fixture, additional infrastructure, installation of fixture, trenching for underground wire connections, and all labor costs (Kula, 2019)
11. Used average cost and number of lights to calculate average cost of lighting system for different scaled systems
12. Estimated LED bulbs to cost €133 (Kula, 2019)
13. Conservatively estimated 12 years as the life span of each bulb (Kula, 2019)
14. Calculated maintenance costs over a 25-year period, assuming each bulb has to be replaced twice in that time period

### Appendix C2: Solar panel specification assumptions and cost estimate calculations

In order to calculate cost estimates for the solar systems, we completed the following steps:

1. Determined the average equivalent wattage output of LED street lights to be 100W, requiring a wattage input of 20W (CREE, 2019)

2. Conservatively used the longest night of the year, 11.5 hours, as our daily hours of usage (“Sunrise and sunset times in Thessaloniki,” 2019)
3. Calculated average daily energy requirements of lights of different scaled systems by multiplying the hours of usage by the wattage input
4. Global Petrol Prices reported the Greek national electricity price average to be €0.18 per kWh (“Greece electricity prices, June 2018 | GlobalPetrolPrices.com,” 2019)
5. Multiplied this by the kWh of electricity needed to calculate annual electricity costs (as if renewable energy were not used, as a return on investment comparison)
6. Conservatively used the shortest day of the year, 9 hours, as the hours of sunlight per day
7. Divided the kWh of electricity usage by 9 hours to determine the wattage needed of entire solar panel system
8. Estimated each solar panel to have a wattage of 0.36 kW, based on the American Mission Solar Energy panels (Wholesale Solar, 2019)
9. Divided total wattage needed by the wattage of a singular panel to determine how many panels are needed
10. Averaged unit and installation cost of Mission Solar Energy panels of €0.60 per watt (Wholesale Solar, 2019)
11. Multiplied total wattage of system by the average cost to determine the upfront cost of the PV system
12. Assumed there would be no maintenance costs in the first 25 years as Mission Solar Energy and many other solar panel companies have a warranty of 30 years for monocrystalline panels
13. Using the daily energy needs of the lighting systems, we used Atlas ESS Batteries with a built-in charge controller which have a rating of 20 kWh and 80% depth of charge
  - a. only 16 kWh would be regularly drawn, which is comparable to the needs of the system
14. The average cost of the batteries is €15798 (Atlas Energy Storage Systems, 2019)
15. We divided the energy required per day by the average 16 kWh that would be drawn, and multiplied it by the average cost of the 20-kWh battery to calculate the estimated price of the battery for each system
16. Estimated the price of inverters to be €0.05 per watt (“Solar Power System Cost Data for recent installations,” 2019)
17. Multiplied the electricity needs of the lighting system by the individual inverter cost to get the total inverter cost
18. We added the PV panels, batteries, and inverters to get the total cost of the photovoltaic system
19. Lastly, we used the annual electricity costs over a 25-year period and the entire cost of the PV system to calculate the payback period of the system

## Appendix D: Detailed calculation table

	Zone				Total	Recommended Area	Pilot System
	1	2	3	4			
Length of road (m)	1563	1151	488	296	3498	1371	60
Width of road (m)	6	6	6	6	6	6	30
Area of road (m <sup>2</sup> )	9378	6906	2928	1776	20988	8224.5	1800
Distance between lights (m)	18	18	18	18	18	18	18
Number of lights required	87	64	27	16	194	76	10
One time costs of installation and lights	€ 309,126.67	€ 227,642.22	€ 96,515.56	€ 58,542.22	€ 691,826.67	€ 271,103.89	€ 35,600.00
Maintenance costs per every 25 years	€ 11,592.25	€ 8,536.58	€ 3,619.33	€ 2,195.33	€ 25,943.50	€ 10,166.40	€ 1,335.00
Wattage (kW)	1.737	1.279	0.542	0.329	3.887	1.523	0.2
Usage (hours)	11.5	11.5	11.5	11.5	11.5	11.5	12.5
Energy required per day (kWh)	19.97	14.71	6.24	3.78	44.70	17.52	2.5
Electricity cost per day	€ 3.55	€ 2.62	€ 1.11	€ 0.67	€ 7.96	€ 3.12	€ 0.45
Electricity cost per year	€ 1,297.56	€ 955.53	€ 405.12	€ 245.73	€ 2,903.94	€ 1,137.96	€ 162.43
Solar panel wattage (kW)	0.36	0.36	0.36	0.36	0.36	0.36	1.36
Capital cost and installation of solar panels	€ 1,342.98	€ 988.98	€ 419.31	€ 254.33	€ 3,005.60	€ 1,177.80	€ 168.11
Space required (m <sup>2</sup> )	33.29	24.51	10.39	6.30	74.49	29.19	4.17
Number of solar panels needed	20	15	6	4	45	18	3
Battery and charge controller cost	€ 19,774.45	€ 14,561.99	€ 6,173.98	€ 3,744.87	€ 44,255.29	€ 17,342.18	€ 2,475.31
Inverter cost	€ 77.28	€ 56.91	€ 24.13	€ 14.64	€ 172.96	€ 67.78	€ 8.90
Total photovoltaic system cost	€ 21,194.71	€ 15,607.88	€ 6,617.41	€ 4,013.84	€ 47,433.85	€ 18,587.75	€ 2,652.32
Total cost of renewable energy lighting system	€ 330,321.38	€ 243,250.10	€ 103,132.97	€ 62,556.06	€ 739,260.51	€ 289,691.64	€ 38,252.32

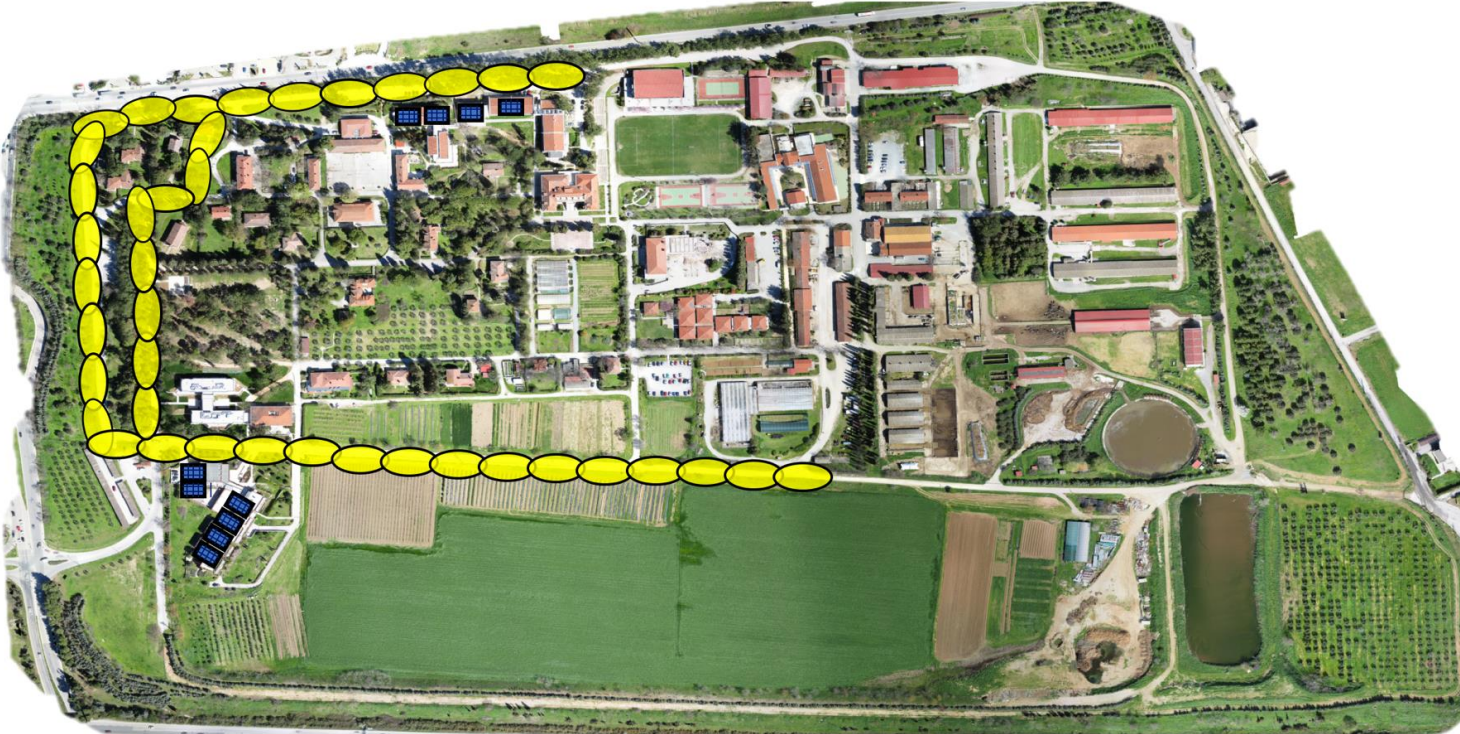


# Appendix E: Location of lights and solar panels

Pilot System:



Recommended System:

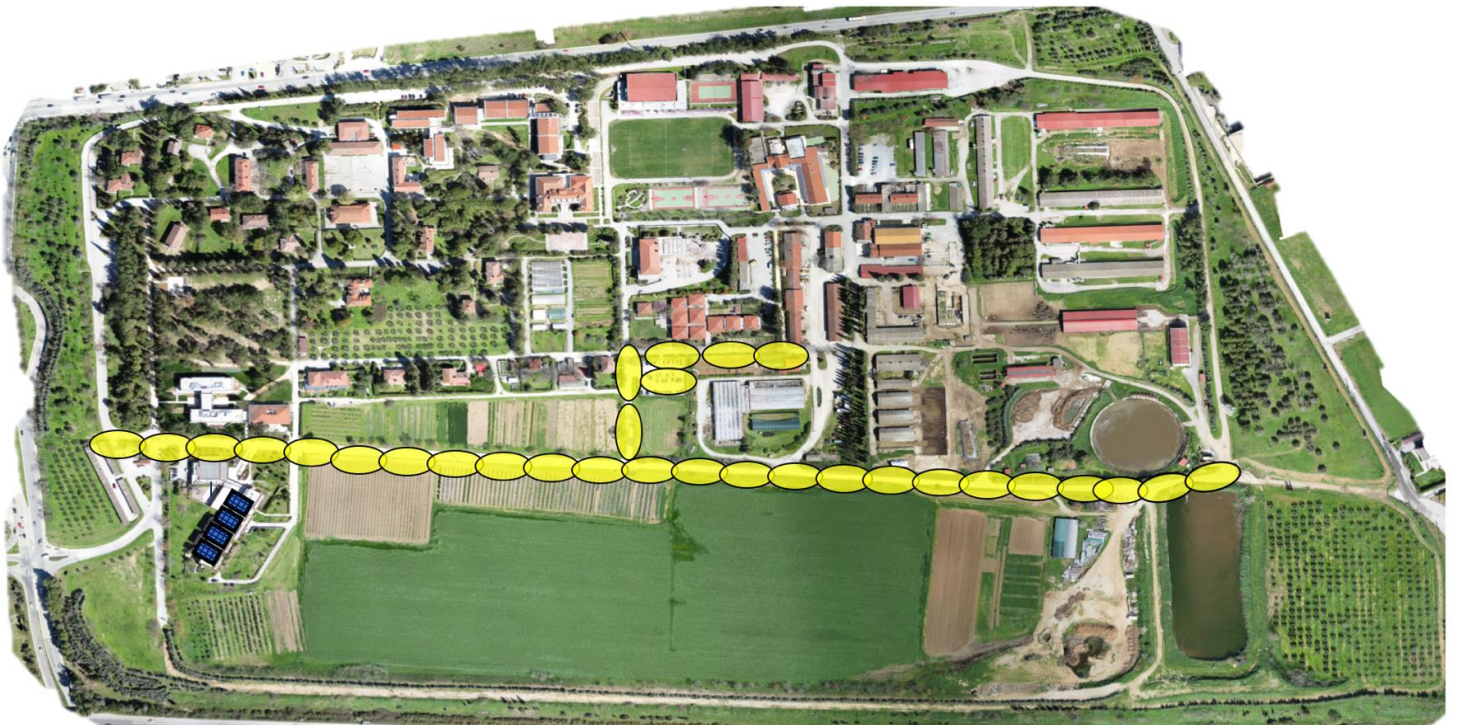




Zone 1:



Zone 2:





Zone 3:

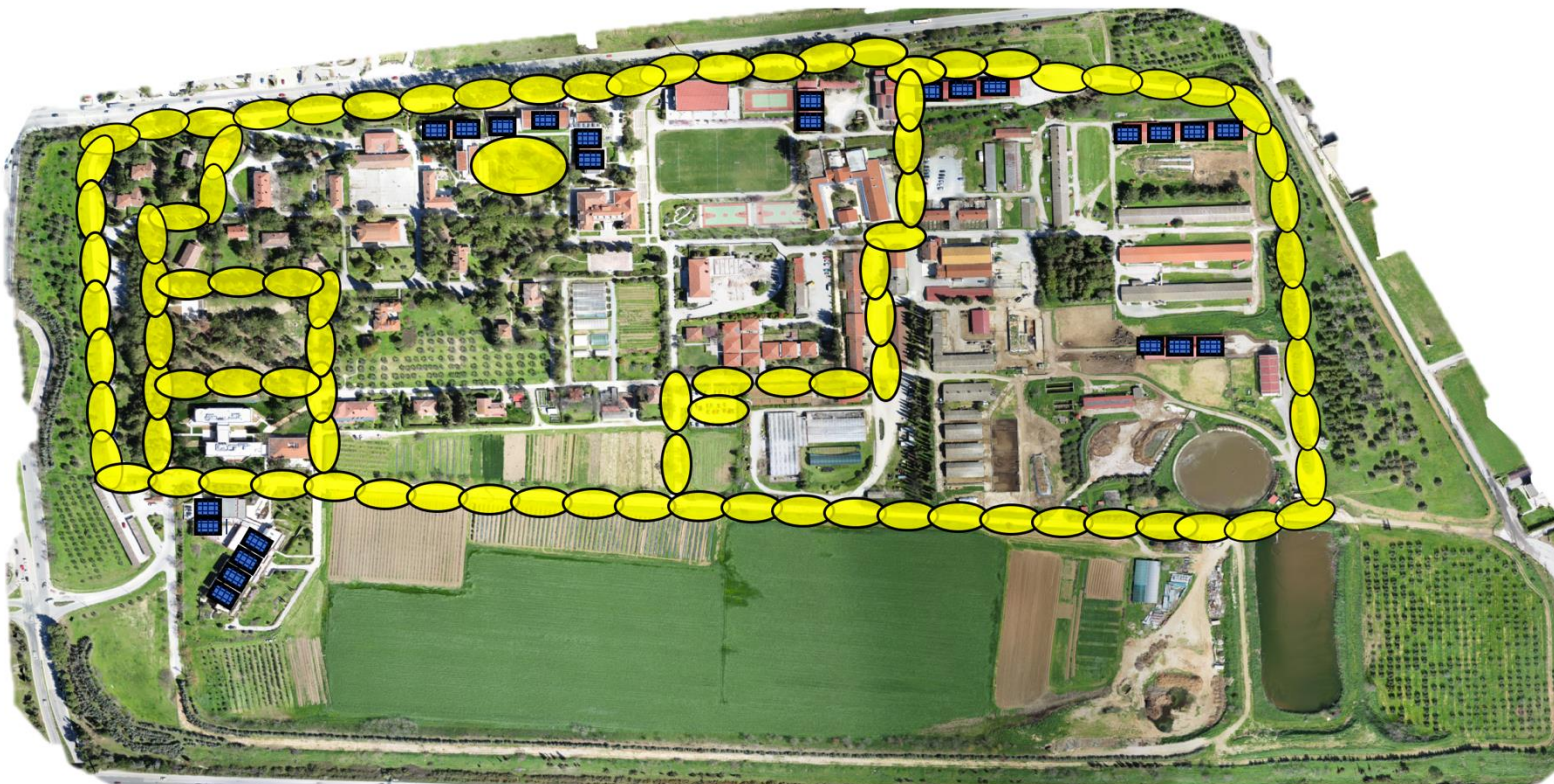




Zone 4:



Total System:





# Appendix F: Measurements of priority roads

## Appendix F1: Zone 1

Total road distance: 1563.09 meters





## Appendix F2: Zone 2

Total road distance: 1151.07 meters



## Appendix F3: Zone 3

Total road distance: 487.90 meters



## Appendix F4: Zone 4

Total road distance: 296.19 meters

